



# High-Resolution Rapid Refresh (HRRR) Program Review

*Assimilation and Modeling Branch  
Global System Division  
NOAA Earth System  
Research Laboratory*  
*March 13, 2012*





# HRRR Program Review Outline

<b>1:30</b>	<b>Opening Remarks</b>	<b>Stan Benjamin</b>
<b>1:30 – 1:40</b>	<b>Program Overview</b>	<b>Curtis Alexander</b>
<b>1:40 – 1:50</b>	<b>Initial Conditions: Rapid Refresh</b>	<b>Steve Weygandt</b>
<b>1:50 – 2:00</b>	<b>Model Development</b>	<b>David Dowell</b>
<b>2:00 – 2:10</b>	<b>Case Studies and Applications</b>	<b>Eric James</b>
<b>2:10 – 2:20</b>	<b>Forecast Verification</b>	<b>Patrick Hofmann</b>
<b>2:20</b>	<b>Summary and Future Plans</b>	<b>Curtis Alexander</b>
<b>2:20 – 2:30</b>	<b>Questions</b>	



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# HRRR Program Key Partners

## NOAA/ESRL/GSD/AMB

Stan Benjamin  
Steve Weygandt  
Curtis Alexander  
David Dowell  
Patrick Hofmann  
Eric James  
Brian Jamison  
Susan Sahm  
Kevin Brundage  
Steven Peckham  
John M. Brown  
Tanya Smirnova  
Ming Hu  
Haidao Lin  
Joe Olson  
Tracy Lorraine Smith  
Bill Moninger  
Georg Grell  
Xue Wei  
Bernie Johnson

## NOAA/ESRL/GSD (or HPC)

Bob Lipschutz  
Craig Tierney  
Chris Harrop  
Leslie Hart  
Forrest Hobbs  
John Schneider

## NOAA/ESRL

James Wilczak  
Melinda Marquis  
Sandy MacDonald

## NOAA/NCEP

GSI developers  
Geoff DiMego  
Geoff Manikin  
Dennis Keyser  
John Derber  
Steve Weiss

## NCAR

WRF developers  
DTC developers  
James Pinto  
Matthias Steiner  
Ken Stone

## FAA

Jenny Colavito  
Warren Fellner  
Steve Abelman  
Jaime Figueroa

## MIT/LL

Marilyn Wolfson  
Haig Iskenderian  
Bill Dupree

## DOE

Stan Calvert



# Hourly Updated NWP Models

13km Rapid Refresh (RAP) (mesoscale)

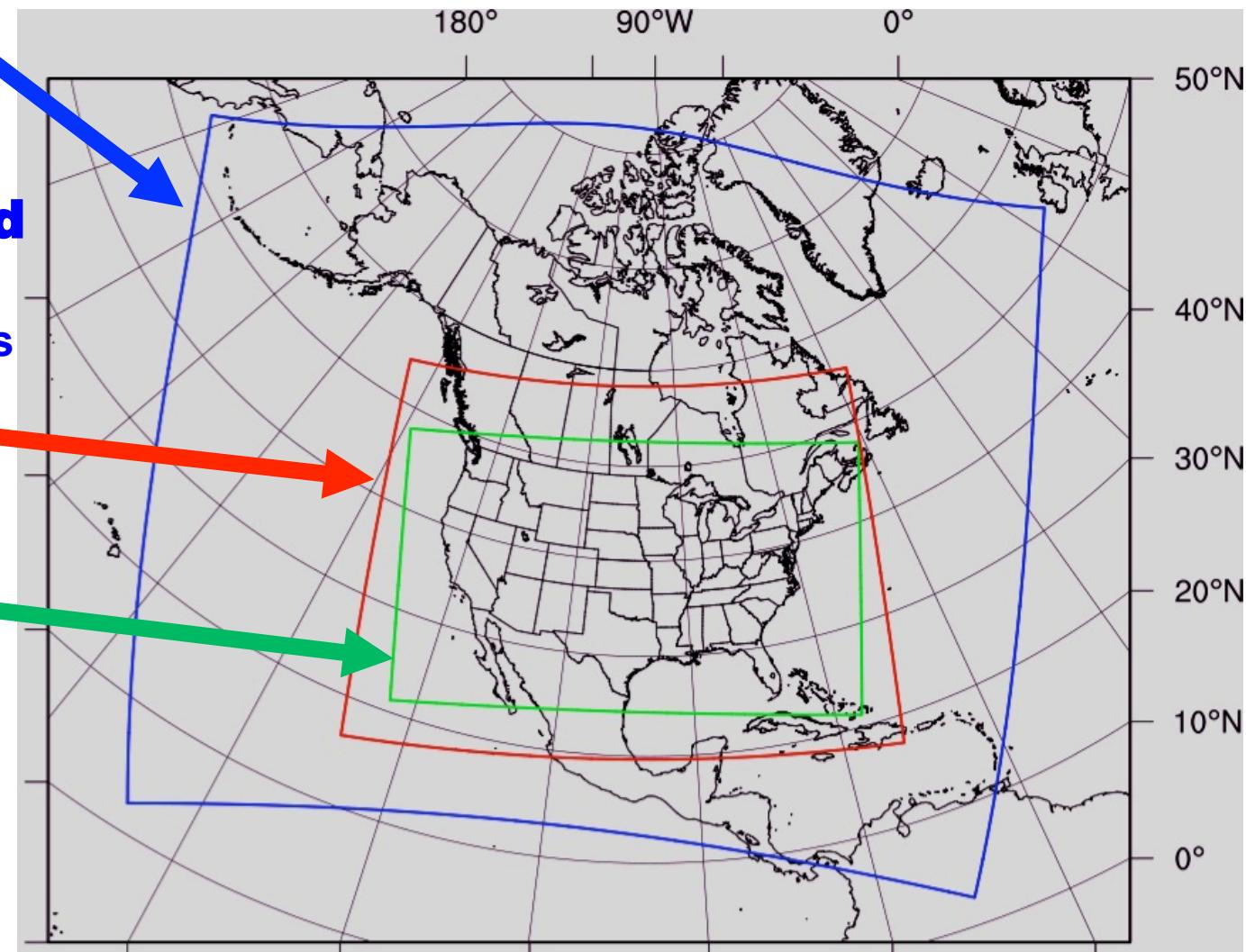
**Replaces RUC at NCEP -planned  
03/20/12**

WRF, GSI, RUC features

13km RUC (mesoscale)

3km HRRR (storm-scale)

High-Resolution Rapid Refresh  
Experimental 3km nest inside RAP,  
hourly 15-h fcst





# HRRR Users and Applications

Aviation Weather Center (AWC): 2-D grids

Federal Aviation Administration (FAA) Command Center

National Center for Atmospheric Research (NCAR): 2-D, 3-D, 15-min grids

Operational evaluation in CoSPA

Storm Prediction Center (SPC): 2-D grids

Operational severe weather forecasting and evaluation

National Severe Storms Laboratory (NSSL): 2-D, 3-D and 15-min grids

Mesoscale analysis, Short-term precipitation forecasts

National Centers for Environmental Prediction (NCEP): 15-min grids

Real Time Mesoscale Analysis (RTMA)

Department of Energy/NOAA Wind Forecast Improvement Project (WFIP)

~12 energy private sector companies via WFIP (WindLogics, 3Tier,

AWS Truepower, Precision Wind, Weather Channel, etc.)

Real-time forecasts of turbine-level wind and solar irradiance

Colorado State University (CSU/CIRA): 2-D grids

Verification of solar irradiance forecasts at SURFRAD sites

Air Resources Laboratory (ARL): Tiled 3-D HRRR grids

Dispersion forecasts, Local wind forecasts in complex terrain

National Weather Service (NWS): 2-D and 3-D grids

Operational weather forecasting

United States Air Force (USAF): 2-D grids

Operational weather forecasting

Aviation

Severe Weather

Renewable Energy

Forecasting



# Evolution of the HRRR

## Historical programmatic decisions

1998	Addition of digital filter initialization (DFI) to RUC model for 1hr cycling
2005	Switch to moist version of DFI in RUC model at NCEP
2007	Availability of national NSSL 3-D radar: <ul style="list-style-type: none"><li>• Recognition of radar assimilation “opportunity” within moist DFI</li><li>• Initial RUC testing of radar-DFI technique, success</li><li>• Recognition of &lt;5km-scale (storm-scale) modeling with RUC radar-DFI analysis using WRF model, initial testing, success</li><li>• Set up initial NE Corridor domain for HRRR</li><li>• Goal: Avoid lateral boundary condition issue for local models</li></ul>
2009-10	Implement radar processing from RUC inside GSI Implement DFI and DFI-radar technique in WRF
2007-09	Increase domain of HRRR based on FAA, NOAA, DOE funding
2011 April	Switch parent model for HRRR from RUC to Rapid Refresh



# Future and Goals of the HRRR

## Current or upcoming decisions in near future

- Details on implementation of HRRR on new HPCS (zeus)
- Interaction with FAA, NWS and HPCS on “hardened” HRRR for HPCS (zeus/jet)

## Ties to larger goals

NOAA Research:

**What improvements to *observing systems, analysis approaches, and models* will allow better analysis/prediction of atmosphere, ocean, and hydro land processes?**

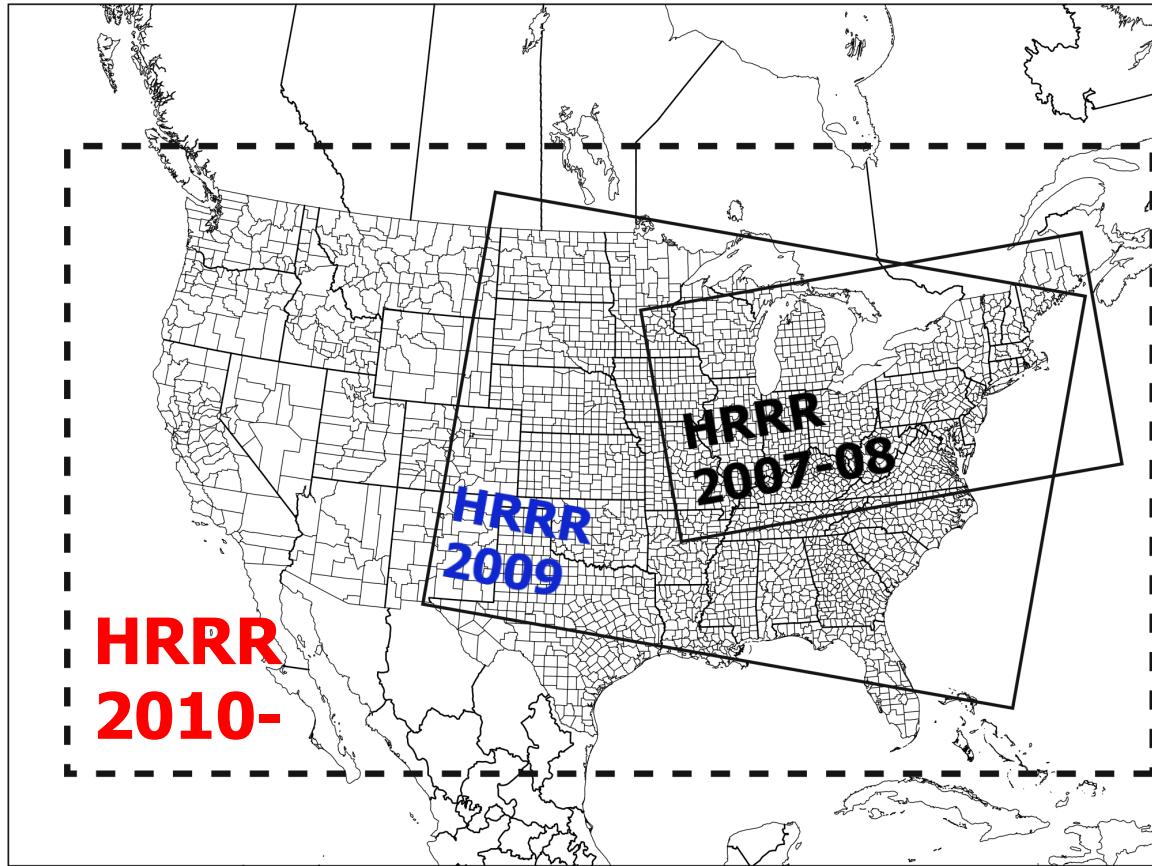
ESRL role:

- Develop new or improved models and assimilation techniques
- Improve prediction and understanding of phenomena
- Support operational forecasting and research
- Apply those “sharpened tools” to --
- Aviation, severe weather, hydrology, energy, other



# Evolution of the HRRR Domain

Hourly frequency maintained



**May – Oct 2010 HRRR run reliability**

**94.5% HRRR completion rate  
(including scheduled downtime)**    **140 TB  
2088 CPUs**

**September 2007**

Initial HRRR domain:  
northeastern United States  
“aviation corridor”

**745 x 383 grid points  
200 processors**

**March 2009**

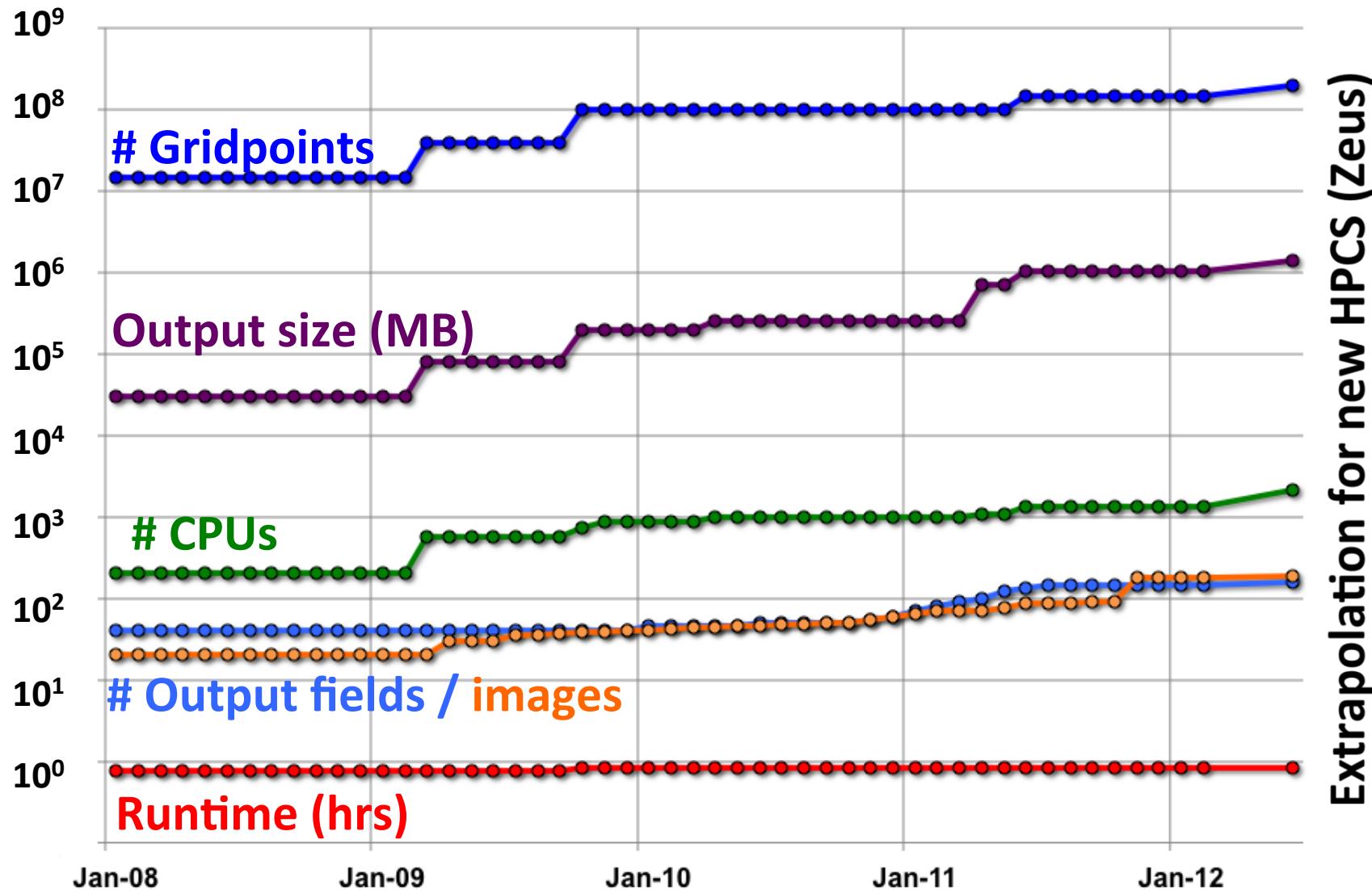
Domain expansion:  
Eastern 2/3 of the US  
1000 x 700 grid points  
**568 processors**

**October 2009**

Domain expansion:  
**CONUS**  
1800 x 1060 grid points  
**15 hour forecasts**  
**1000 processors**



# HRRR Growth





# HRRR Milestones

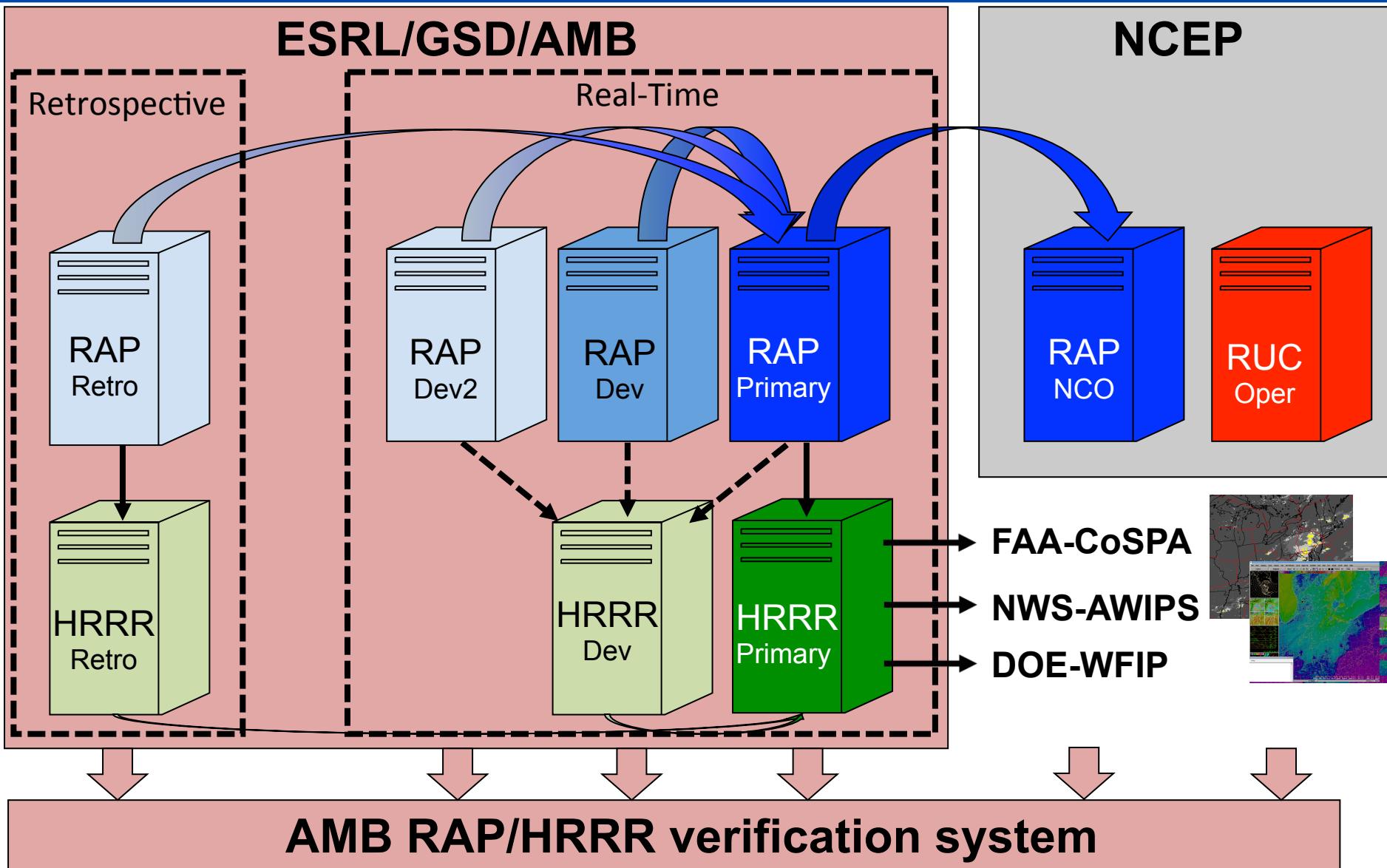
- Inception over northeastern US Sept 2007
- Integration into CoSPA: Aviation Users Spring 2008
- Domain expansion to eastern US Mar 2009
- HCPF time-lagged ensemble inception May 2009
- HRRR WRF-ARW updated to v3.1.1 Oct 2009
- Domain expansion to CONUS Oct 2009
- HRRR WRF-ARW updated to v3.2 Apr 2010
- Forecast period extended to 15 hrs Apr 2010
- Real-time multi-scale reflect. verification June 2010
- Parallel (shadow) retrospective system Sept 2010
- Attained ~95% reliability Jun 2010



# HRRR (and RAP) Milestones

- Reduced latency to ~2 hrs Dec 2010
- Conversion of all output to GRIB2 format Apr 2011
- Transition from RUC to RAP parent model Apr 2011
- DOE-funded HRRR FTP site for energy industry May 2011
- Update to WRF-ARW v3.3.1 Feb 2012
- Rapid Refresh operational at NCEP Mar 2012
- 3-km data assimilation and cycling 2012
- Ensemble Rapid Refresh (NARRE) at NCEP 2014
- HRRR operational at NCEP 2015?
- Ensemble HRRR (HRRRE) at NCEP 2016?

# Model Configurations

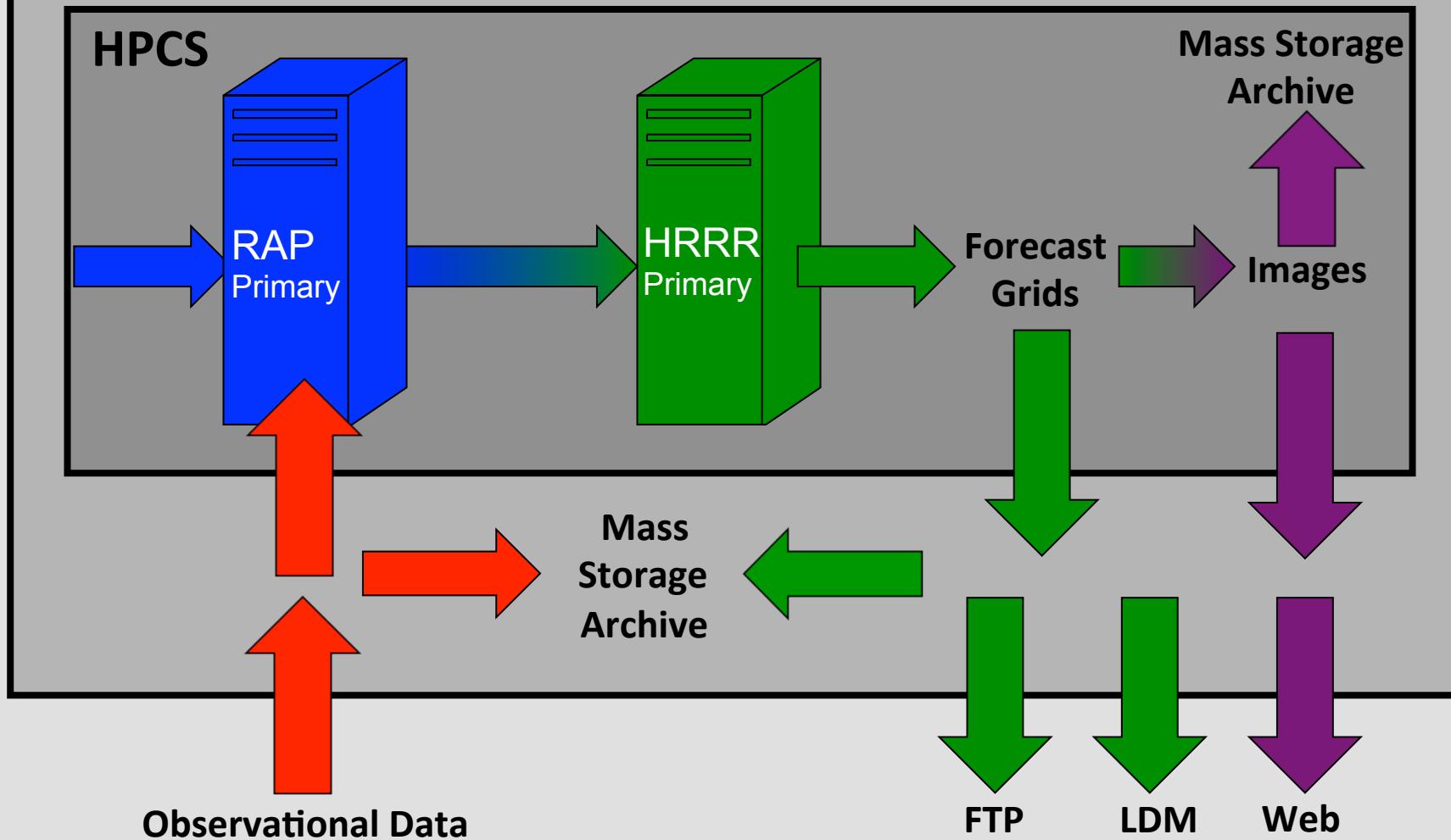




# HRRR Dataflow

## Public Users

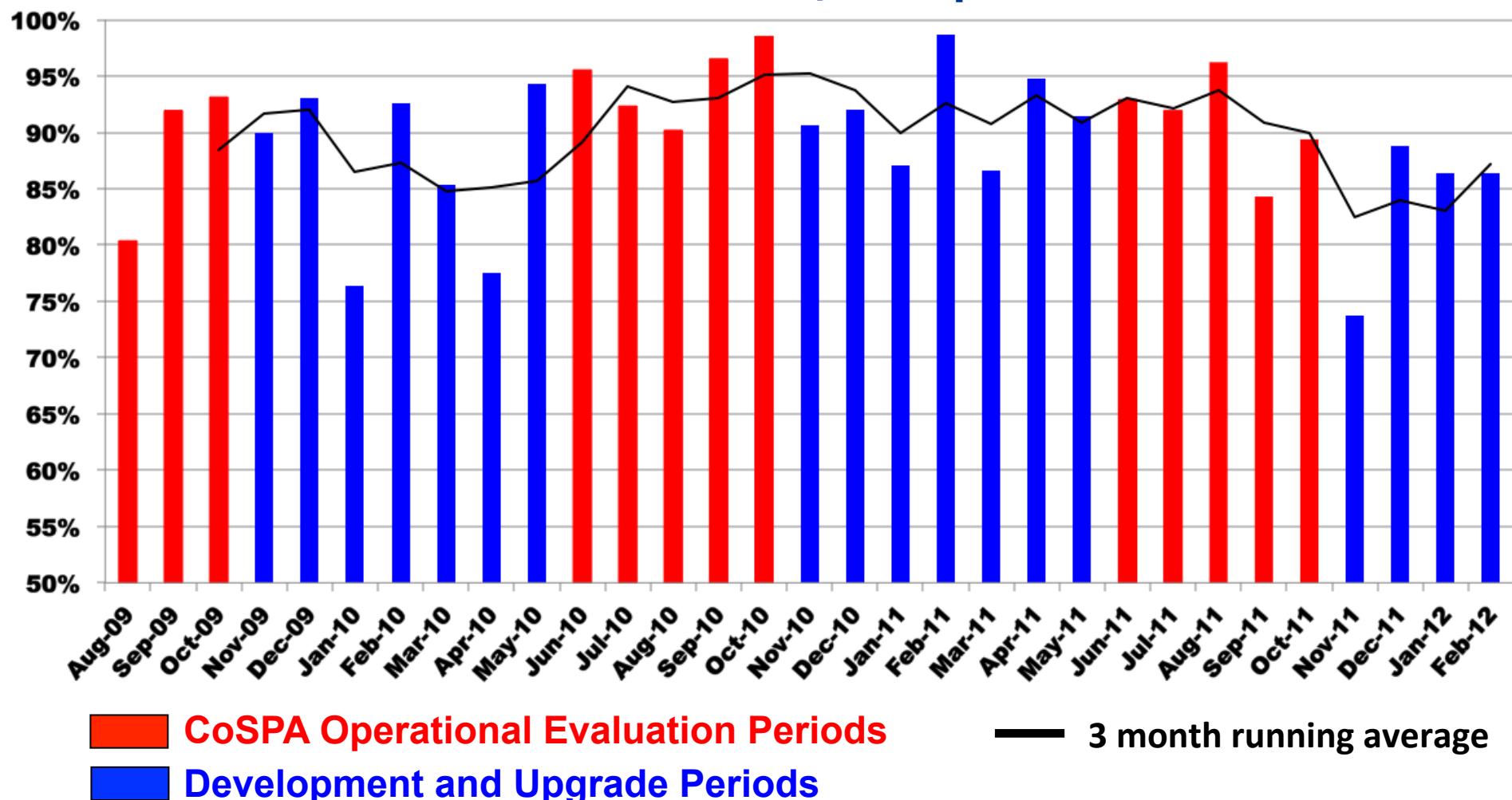
ESRL





# HRRR Reliability

HRRR 12 hr fcst availability  
Includes all missed/incomplete runs



█ CoSPA Operational Evaluation Periods

█ Development and Upgrade Periods

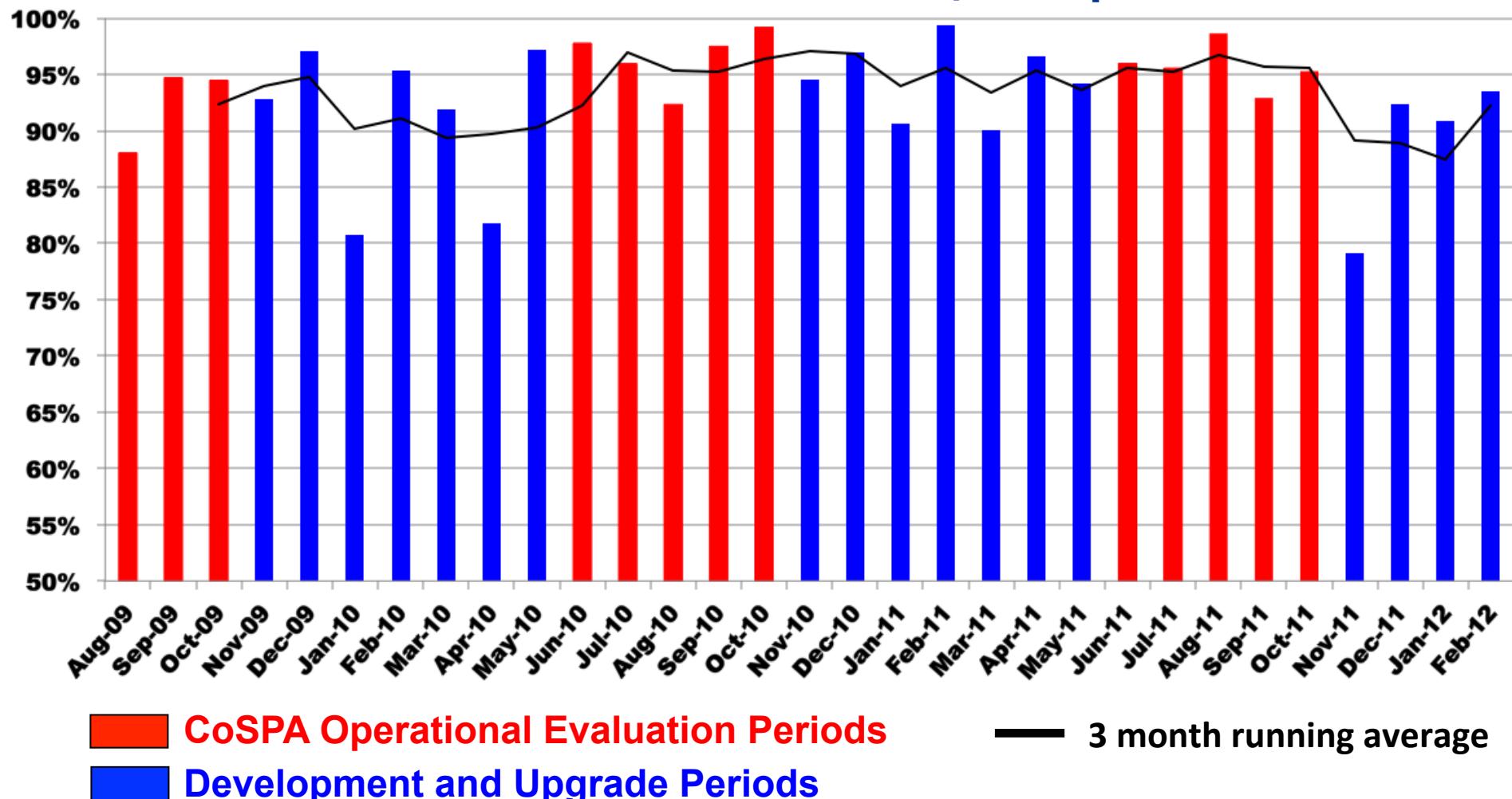
— 3 month running average



# HRRR Reliability

HRRR 12 hr fcst availability

Excludes non-consecutive missed/incomplete runs



█ CoSPA Operational Evaluation Periods

█ Development and Upgrade Periods

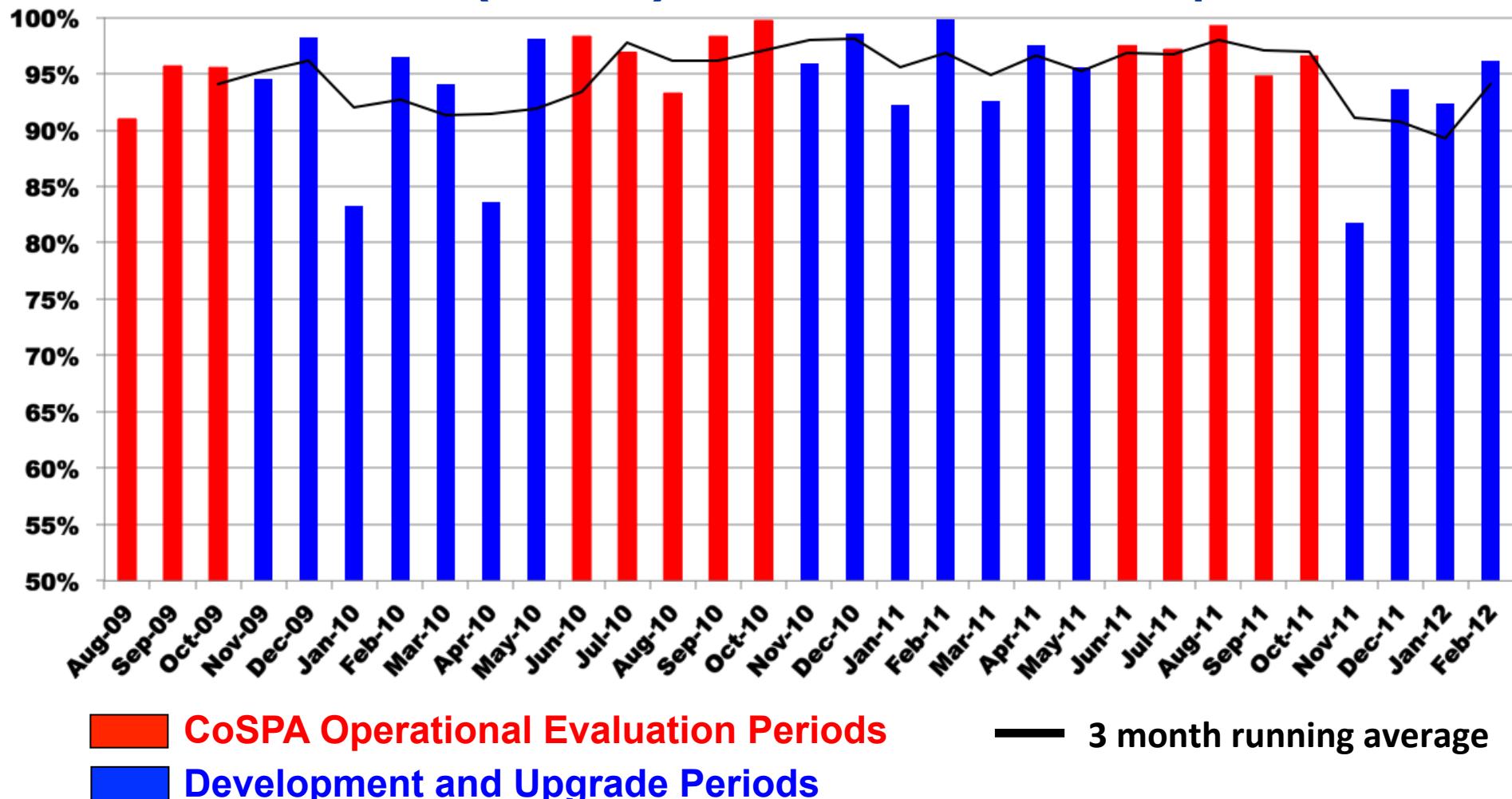
— 3 month running average



# HRRR Reliability

HRRR 12 hr fcst availability

Excludes two (or fewer) consecutive missed/incomplete runs



■ CoSPA Operational Evaluation Periods

■ Development and Upgrade Periods

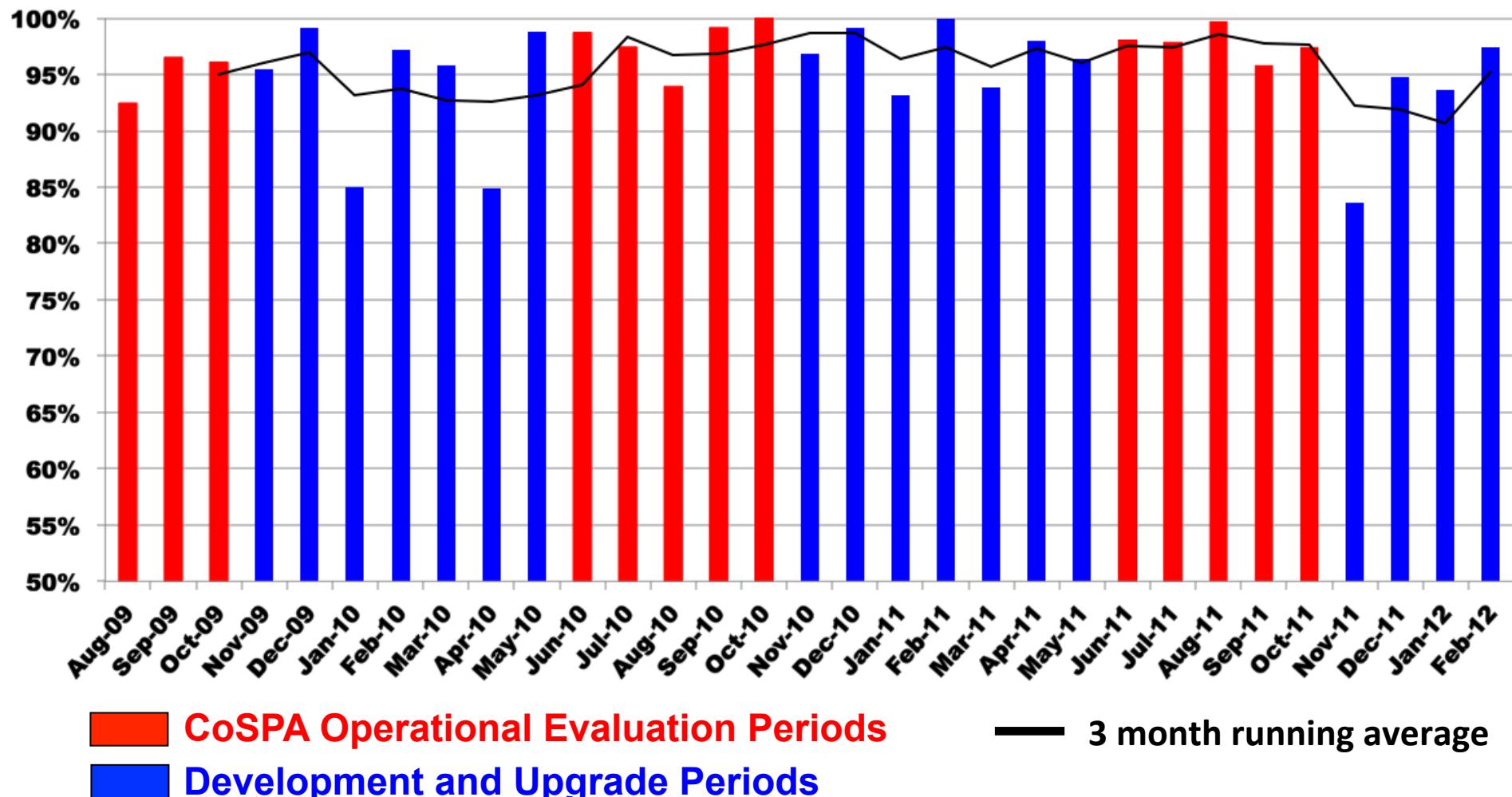
— 3 month running average



# HRRR Reliability

HRRR 12 hr fcst availability

Excludes three (or fewer) consecutive missed/incomplete runs





# HRRR Transition to NCEP

- **Current – 1 computer running HRRR**
  - NOAA/ESRL – Boulder
  - Current reliability: 97% for last 12h months (allowing up to 3h gaps)
- **2012-14 – 2 computers running HRRR – interim solution**
  - Boulder – computer 1
  - Fairmont, WV – computer 2
  - Expected reliability to increase further to 98.5-99% via coordination of downtimes for Boulder vs. Fairmont computers
- **2015 – NCEP running HRRR**
  - NOAA/NCEP computing budget – will allow no increase before 2015
- Conclusion: *Interim HRRR computing for 2012-14 on 2 sites to provide “research regular” HRRR from NOAA for NWS, FAA, DOE/energy users*

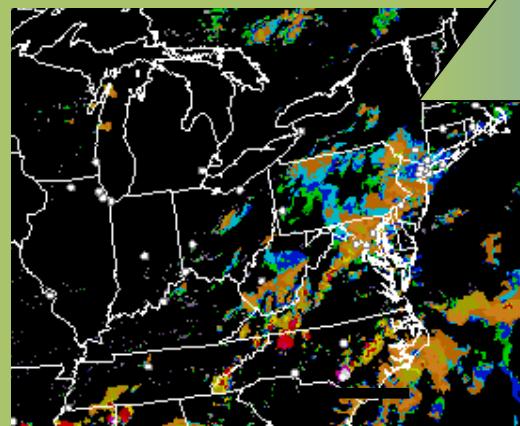
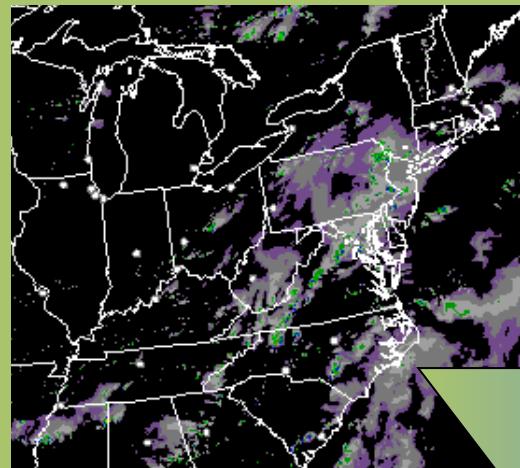


# HRRR Forecasts for Aviation

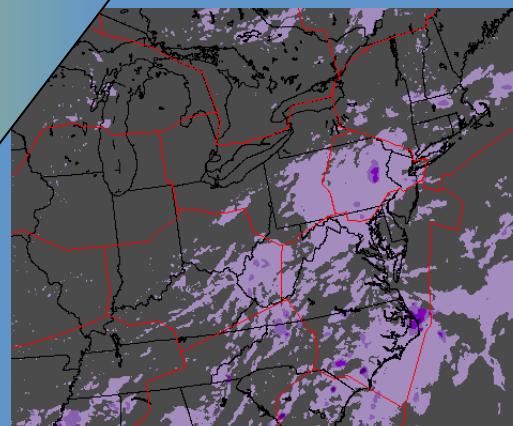
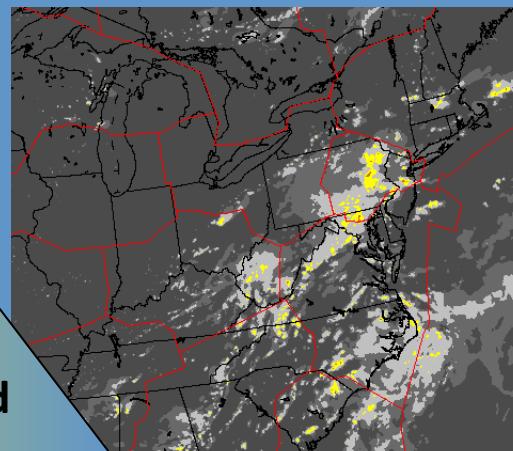
**CoSPA:** Collaborative effort: ESRL/GSD, NCAR/RAL, MIT/LL

Provide 0-8 hr thunderstorm intensity and echo top guidance to aviation community

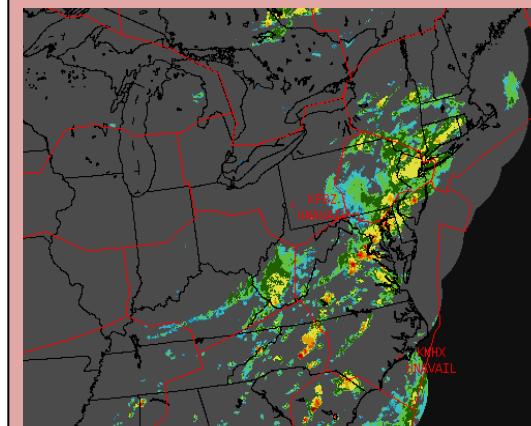
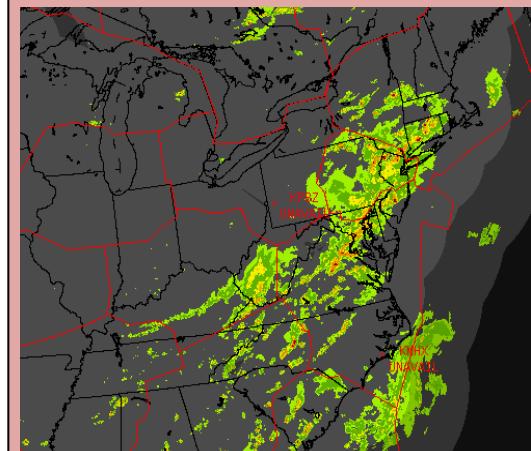
**HRRR 15 UTC 08 July 2011**  
6 hr forecast valid 21 UTC



**CoSPA 17 UTC 08 July 2011**  
4 hr forecast valid 21 UTC



**Observation**  
Valid 21 UTC 08 July 2011

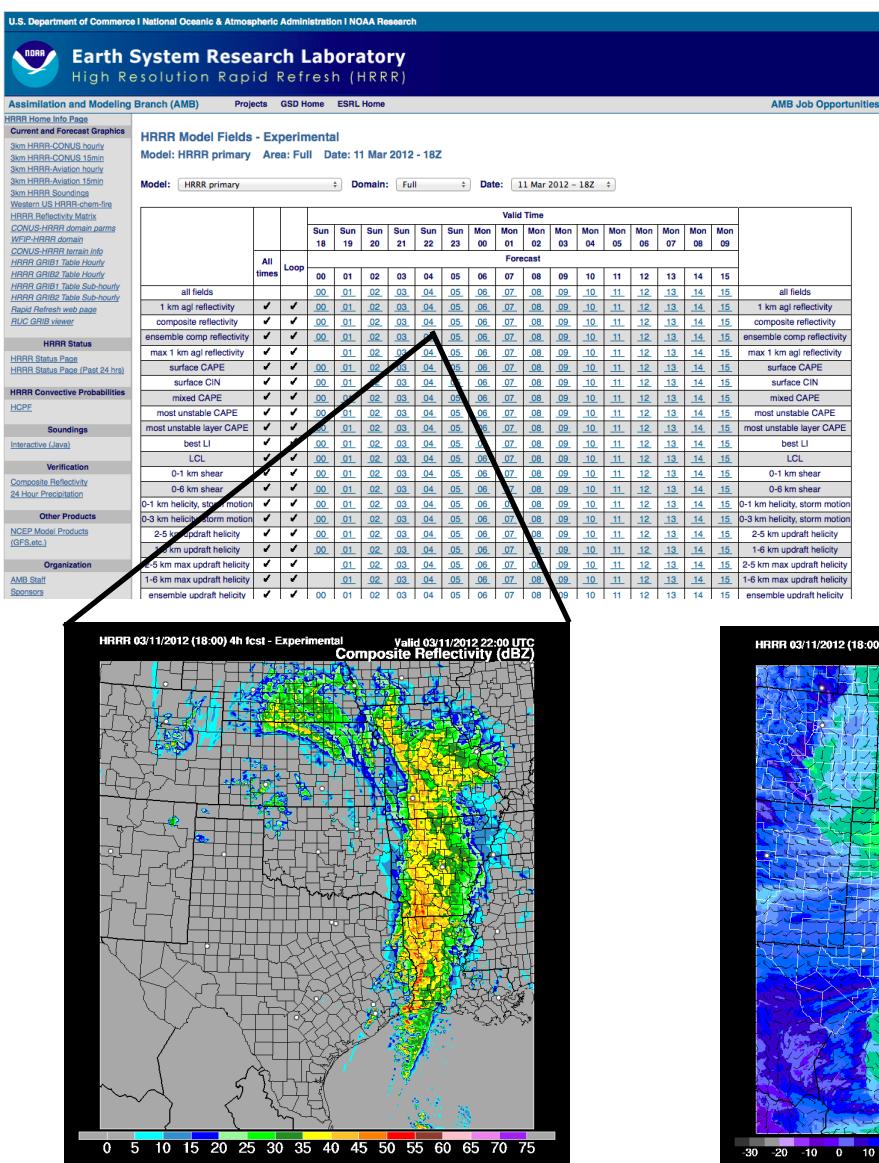


Blend  
with  
CIWS

VIL  
  
Echo Top

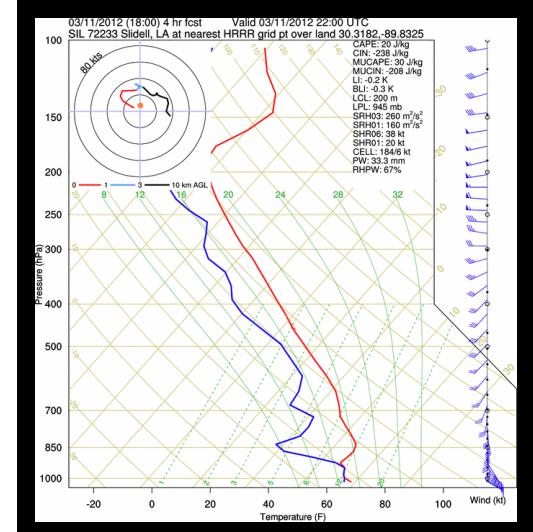


# HRRR Websites



**HRRR Web Pages:**  
**Hourly Plan-View Forecast Fields**  
**Sub-Hourly Plan-View Forecast Fields**  
**Sounding Forecasts**

<http://rapidrefresh.noaa.gov/hrrrconus/>  
<http://rapidrefresh.noaa.gov/hrrrconus15min/>  
<http://rapidrefresh.noaa.gov/soundings/>





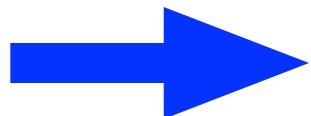
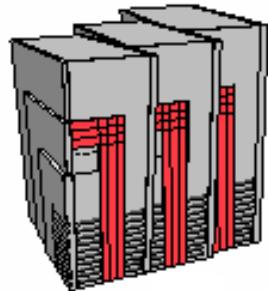
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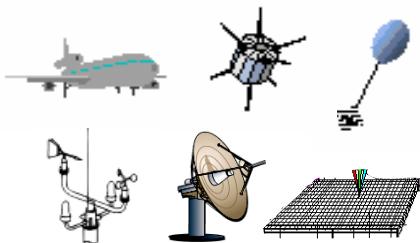


# RAP: Data assimilation engine for HRRR

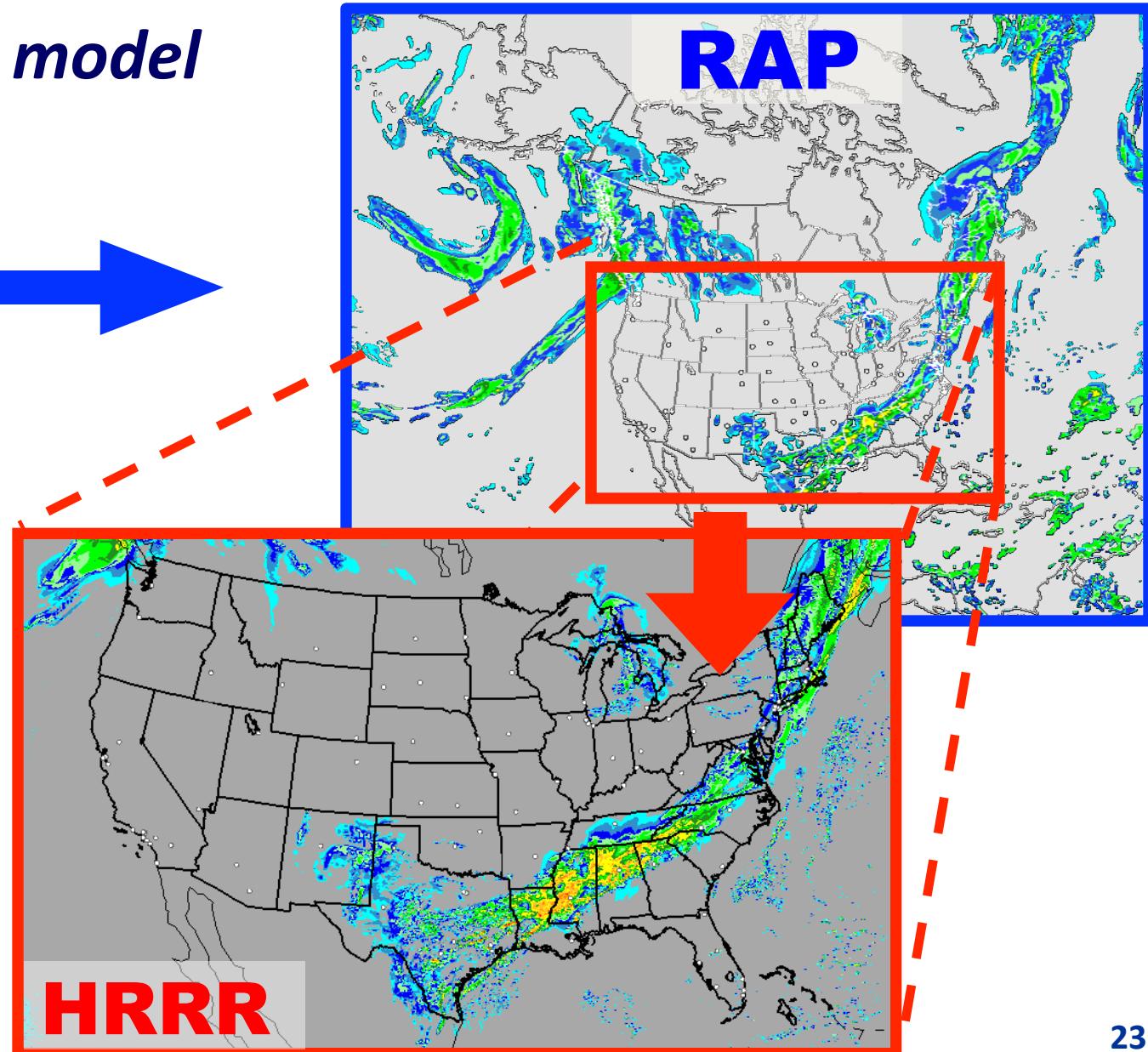
*Hourly cycling model*



Data  
Assimilation  
cycle



Observations





# Rapid Refresh and HRRR NOAA hourly updated models

**NCEP**

**RUC → Rapid Refresh (March 20, 2012)**

- Advanced community codes (**ARW and GSI**)
- Retain key features from RUC analysis / model system  
(hourly cycle, radar DFI assimilation, cloud analysis)
- **RAP guidance for aviation, severe weather, energy applications**

**GSD**

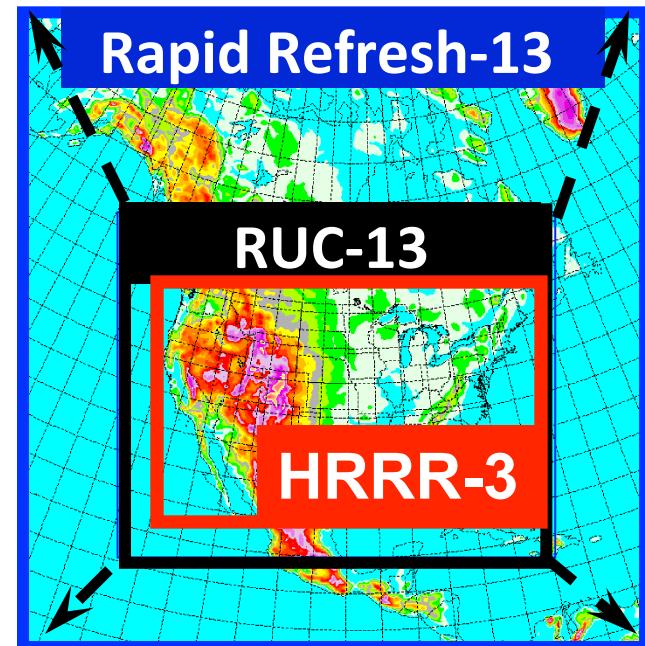
**Rapid Refresh v2**

- Many improvements, target NCEP implement early 2013?

**GSD**

**HRRR**

- Runs as nest within RAP v2

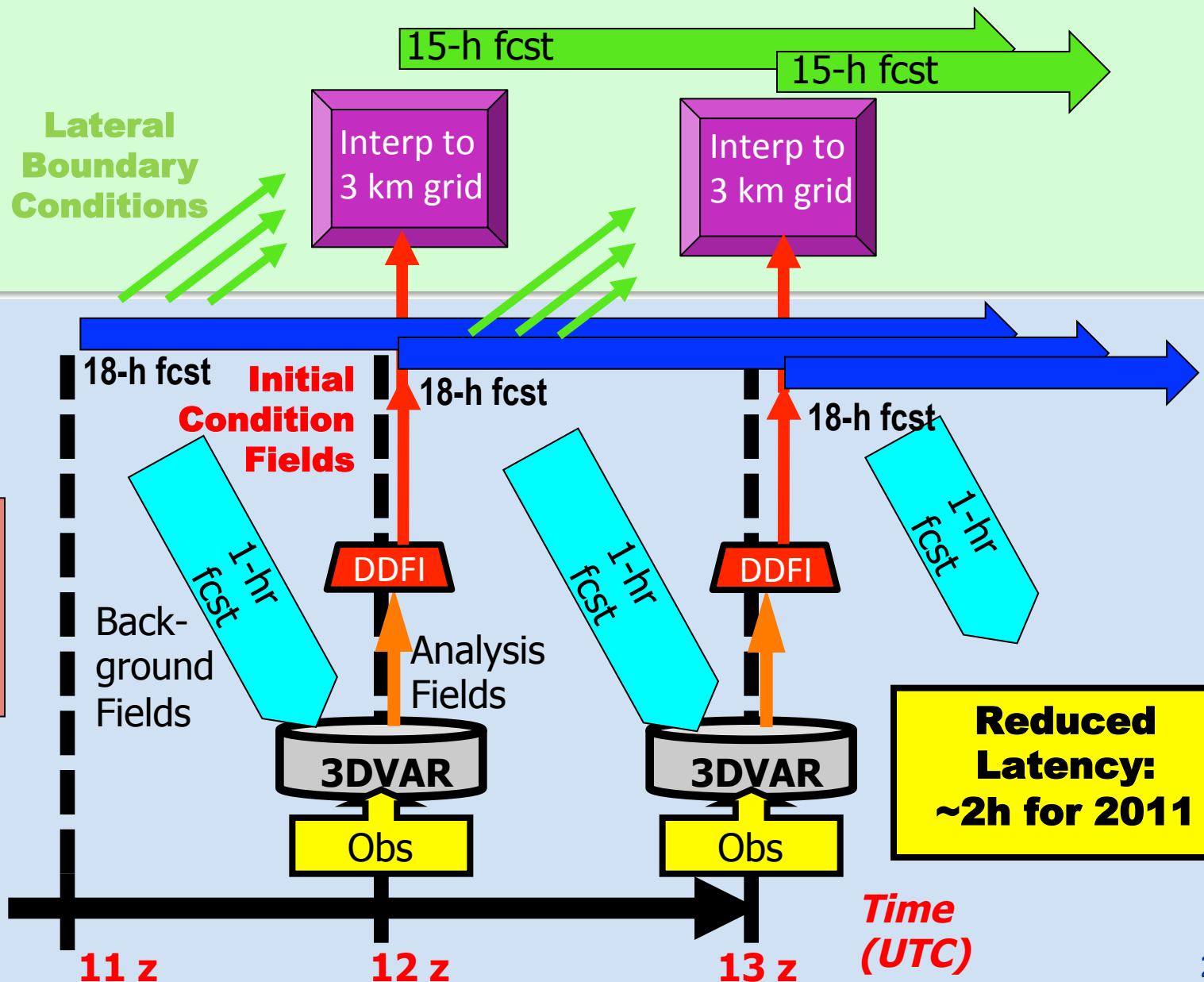




# Hourly HRRR Initialization from RAP

## Hourly HRRR

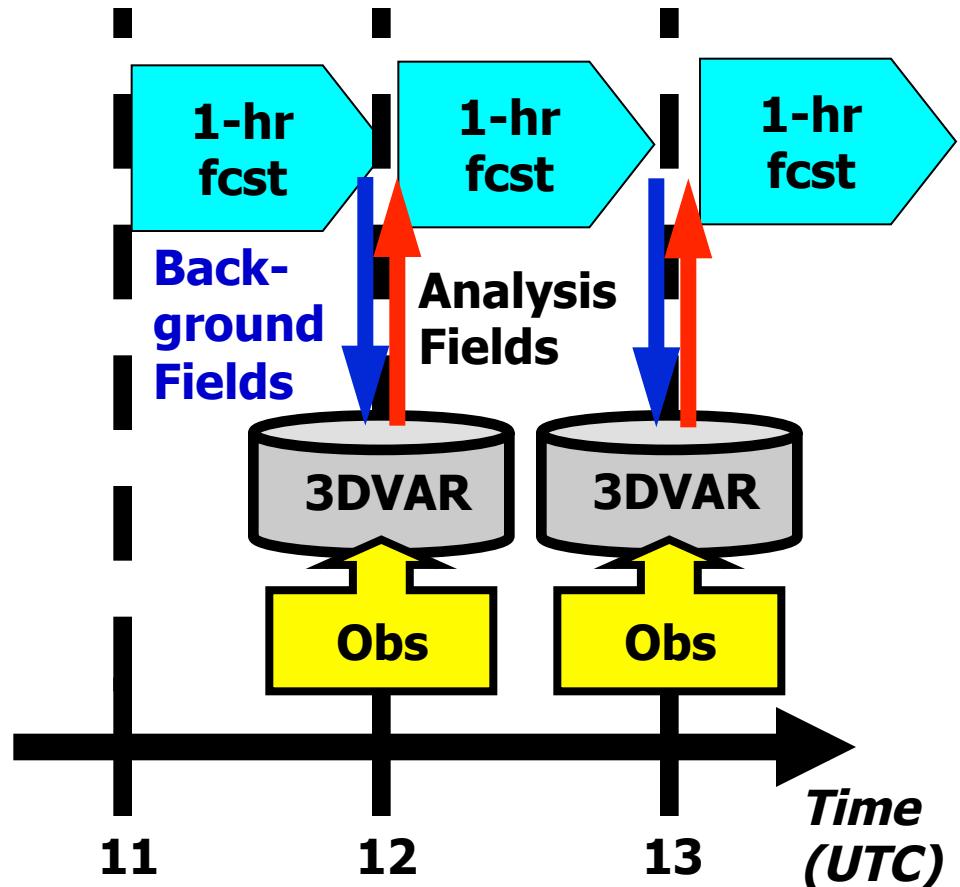
Use 1-h old LBC to reduce latency



# Rapid Refresh

## Update cycle

Cycle hydrometeors  
 Cycle soil temp., moisture, snow



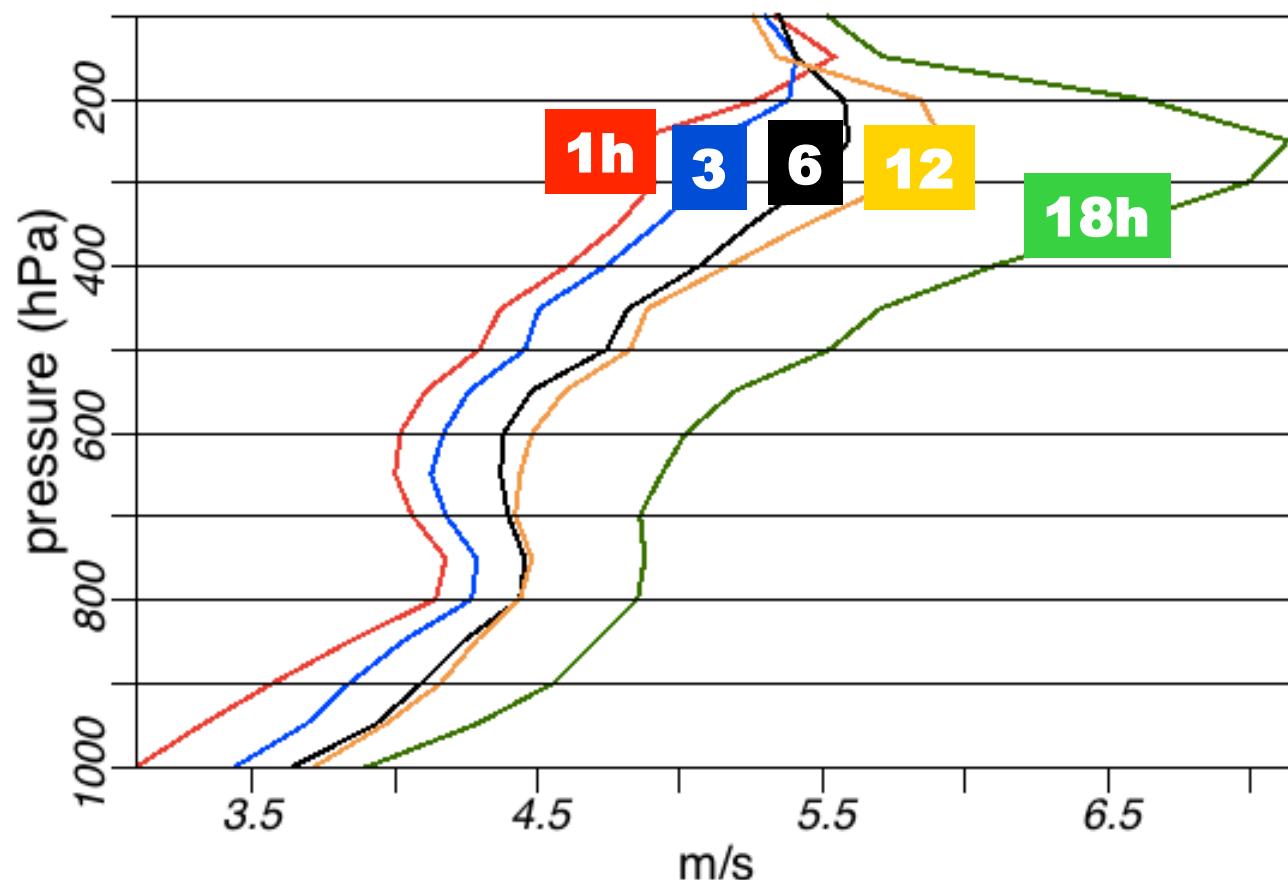
RAP hourly counts (ESRL only)	
<u>Observations / hour</u>	
Rawinsonde (12h)	120
NOAA profilers	21
VAD winds	~125
PBL – profiler/RASS	~25
Aircraft (wind, temp)	2K-15K (avg 7K)
Aircraft-WVSS (RH)	0-800 (avg 520)
Surface/METAR	~2500
Buoy/ship	200-400
GOES cloud winds	4000-8000
GOES cloud-top pres	10 km res
GPS precip water	~260
Mesonet (temp, dpt)	~8000 (fall 12)
Mesonet (wind)	~4000 (fall 12)
METAR-cloud-vis-wx	~2000
AMSU-A/B/HIRS/etc. radiances	
GOES radiances	fall 12
Radar reflectivity	1km
Lightning (proxy refl)	NLDN, GLD360
Radar radial wind	level 2.5
Nacelle/tower/sodar	20/100/10



# RAP error reduction to 1-h forecast

## Rapid Refresh Wind forecast accuracy vs. forecast length

1 Jan -  
7 Mar 2012  
- Verification against  
raobs



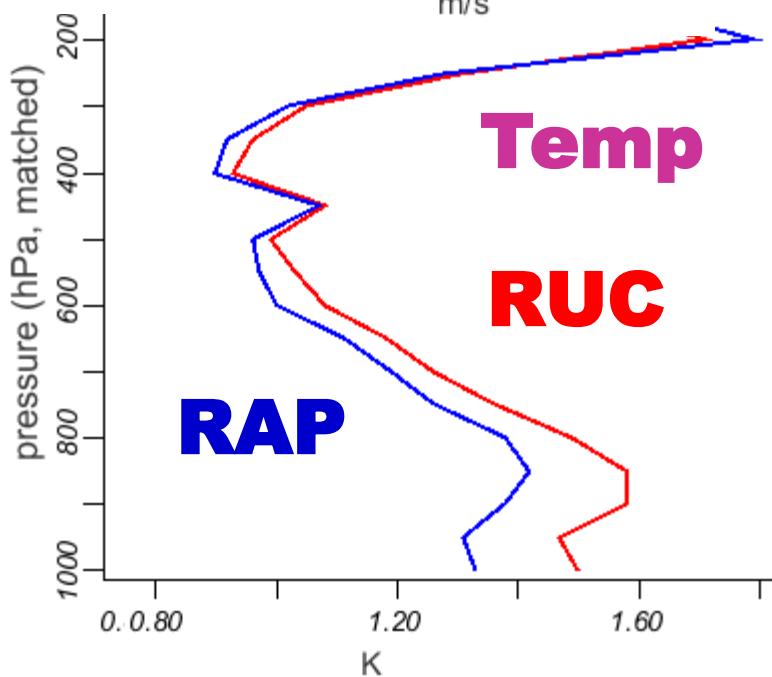
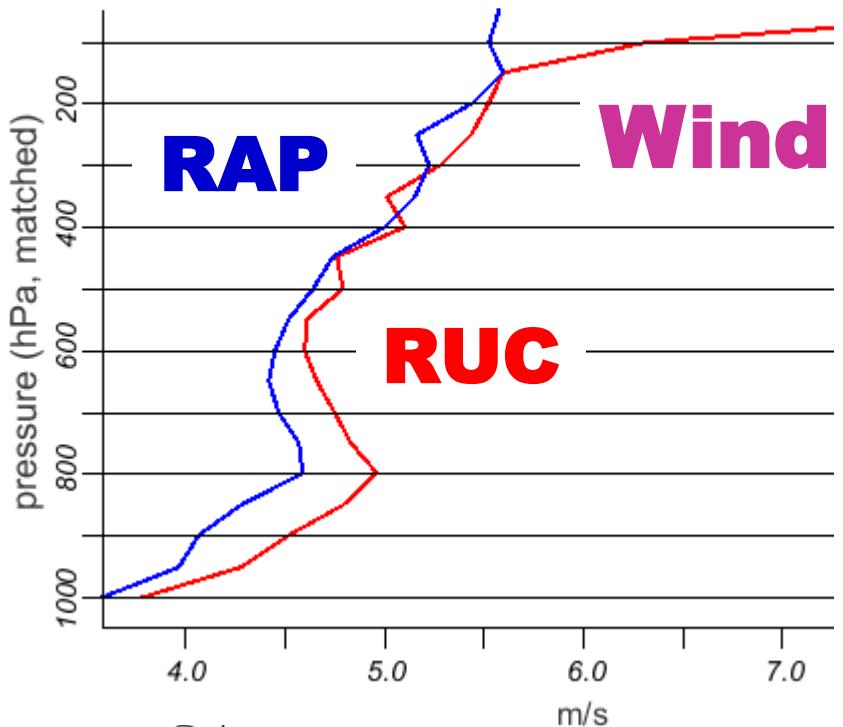
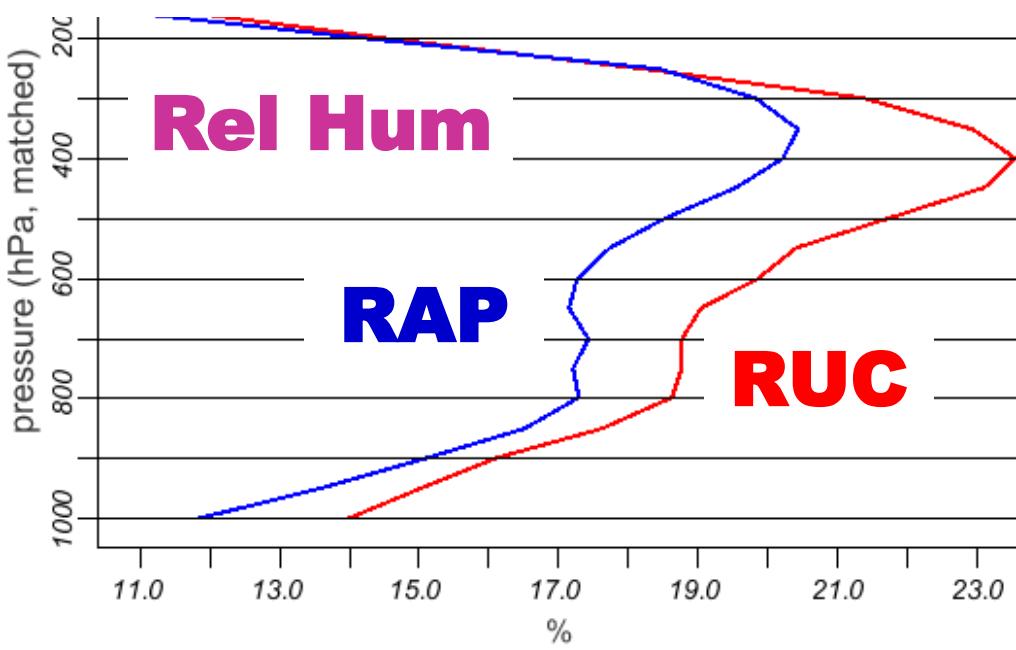
**The Rapid Refresh is able to use recent obs to improve forecast skill down to 1-h projection**

# RUC vs. RAP

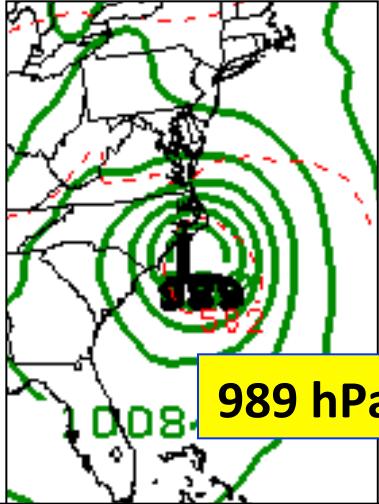
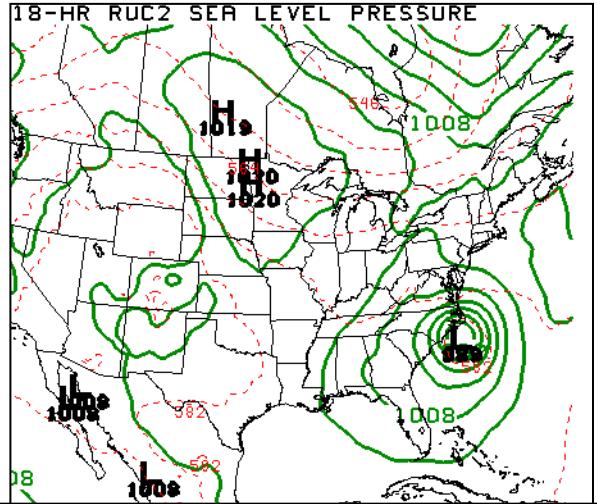
## upper-air verification

+ 3h forecast  
RMS Error

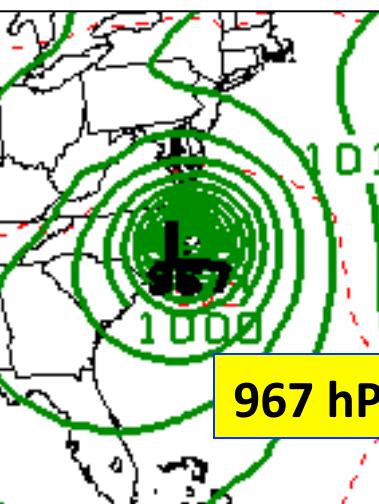
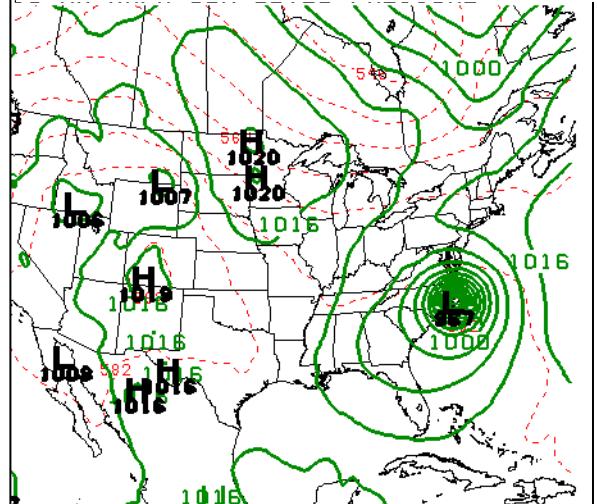
15 Feb 2012 – 8 March 2012



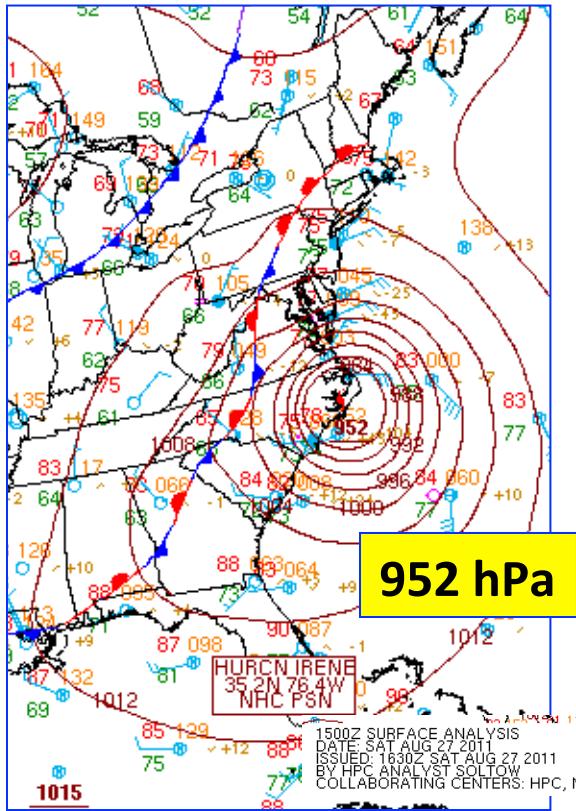
# RUC 18h fcst



# RAP 18h fcst



# Hurricane Irene



**Observations**  
15z Sat 27 Aug 2011

**RAP much improved for tropical systems (partial cycling with GFS), much better RTMA background for TC cases**

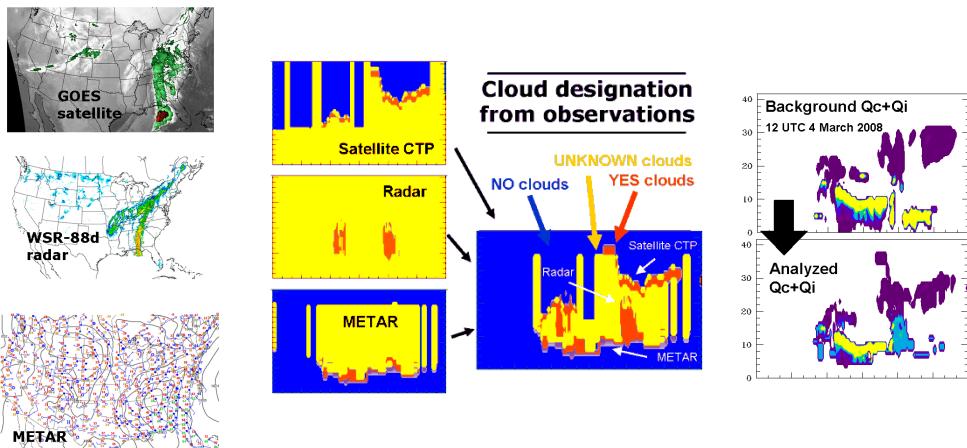


# TC improvement: RAP → HRRR

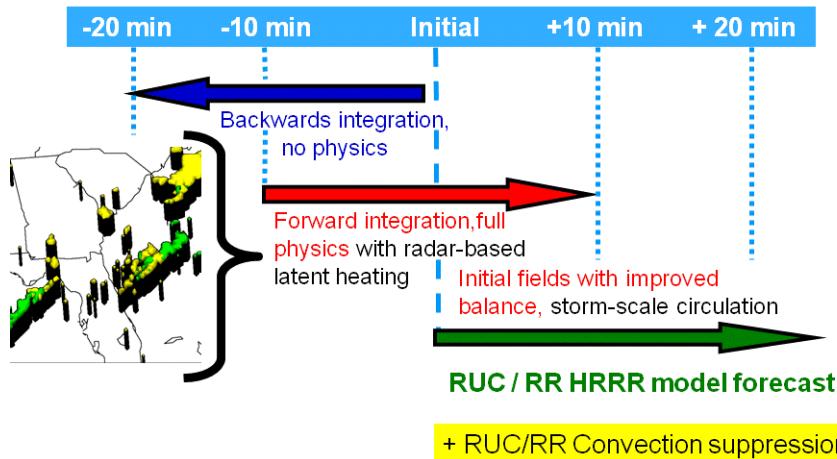
**Comparison of HRRR forecast reflectivity  
(with 15-min output frequency)  
and observed reflectivity for Hurricane Irene**

# Rapid Refresh – specific analysis features

## Cloud and hydrometeor analysis



## Digital filter-based reflectivity assimilation



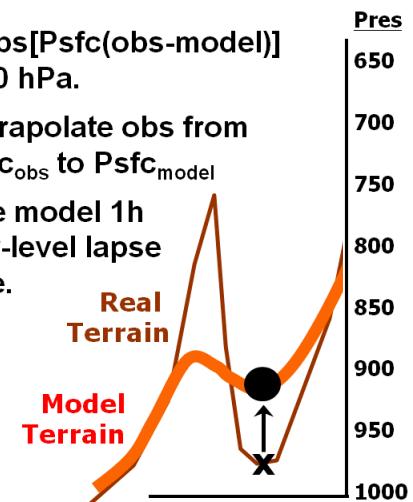
## Special treatments for surface observations

### Elevation correction

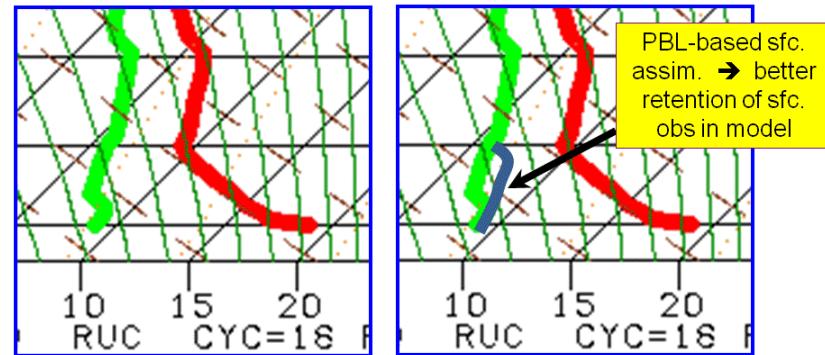
If  $\text{abs}[\text{Psfc}(\text{obs-model})] < 70 \text{ hPa}$ .

Extrapolate obs from  $\text{Psfc}_{\text{obs}}$  to  $\text{Psfc}_{\text{model}}$

Use model 1h low-level lapse rate.

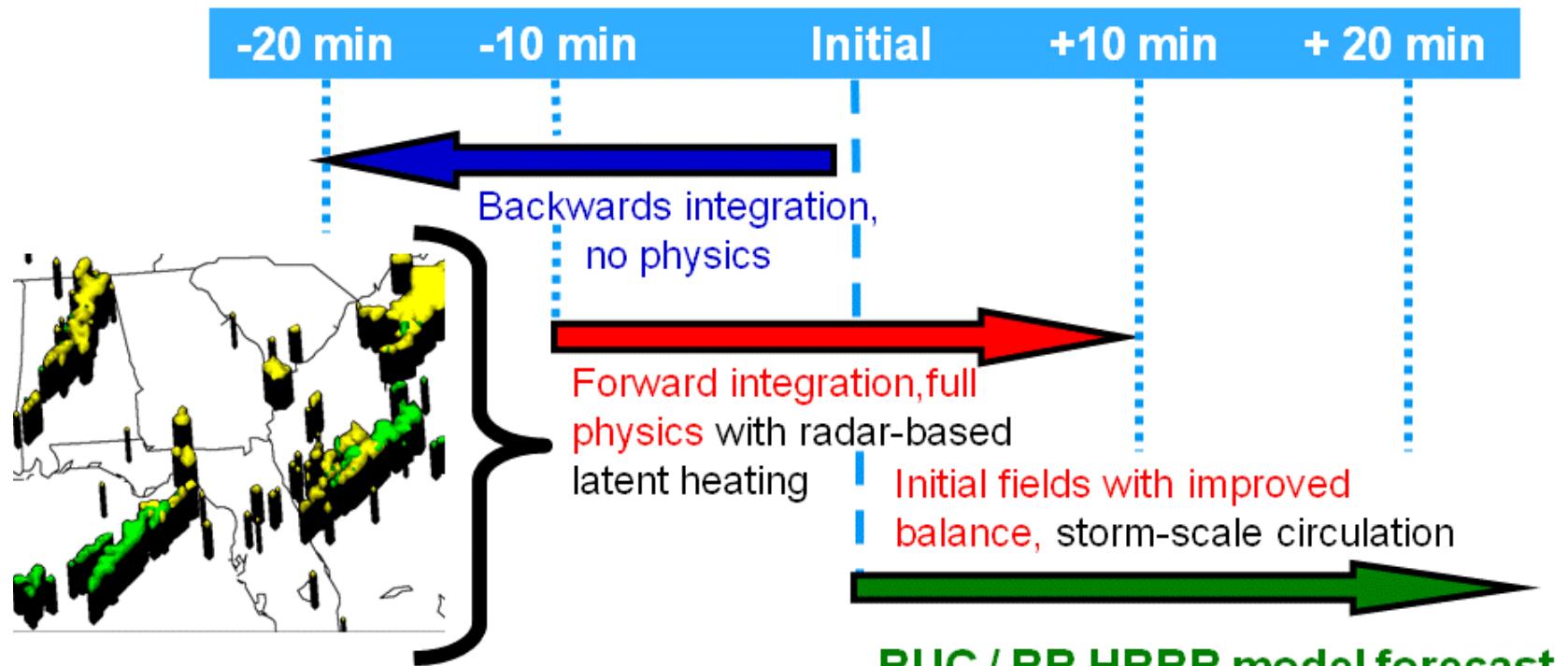


### PBL-based pseudo-observations



# Rapid Refresh – specific analysis features

## DFI-radar reflectivity assimilation

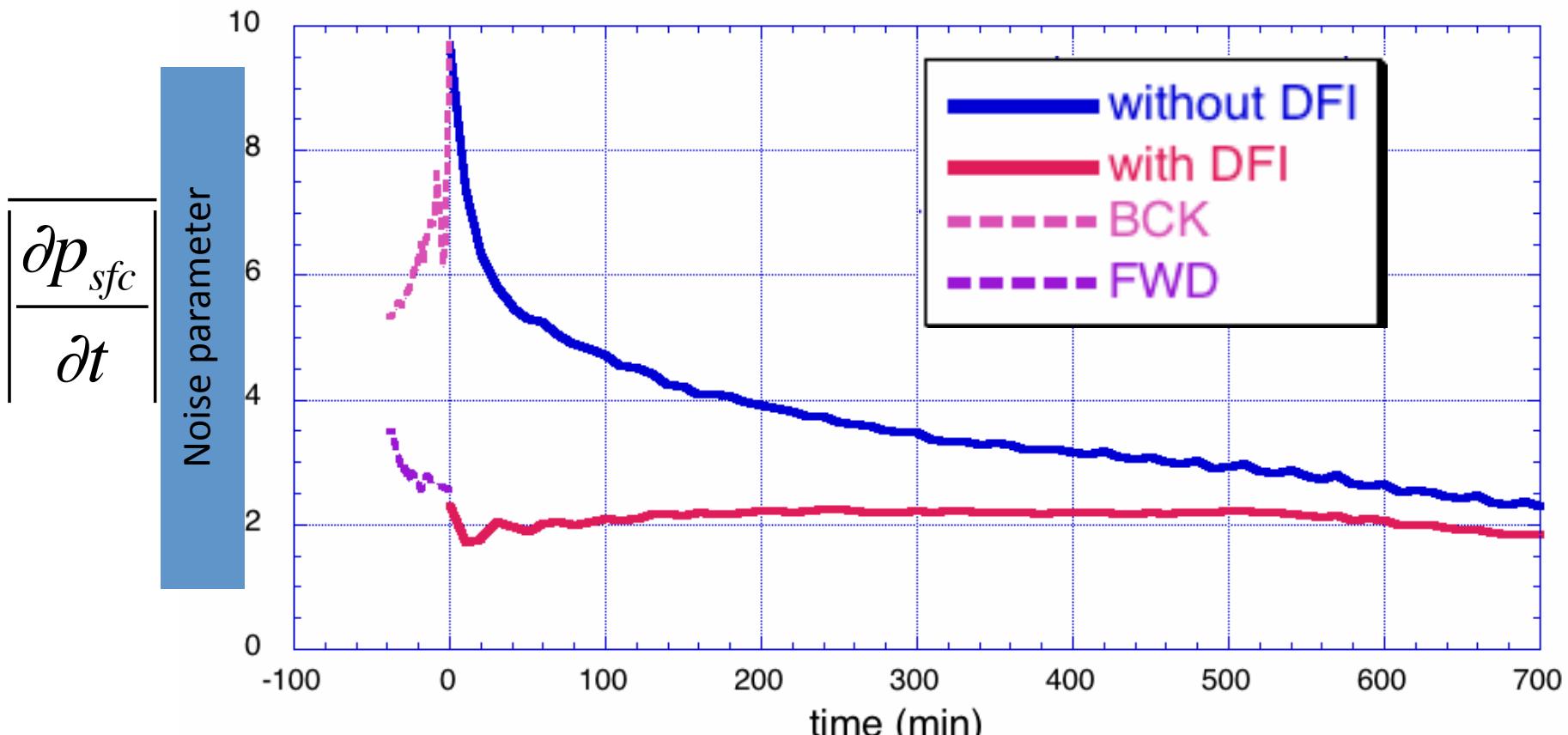


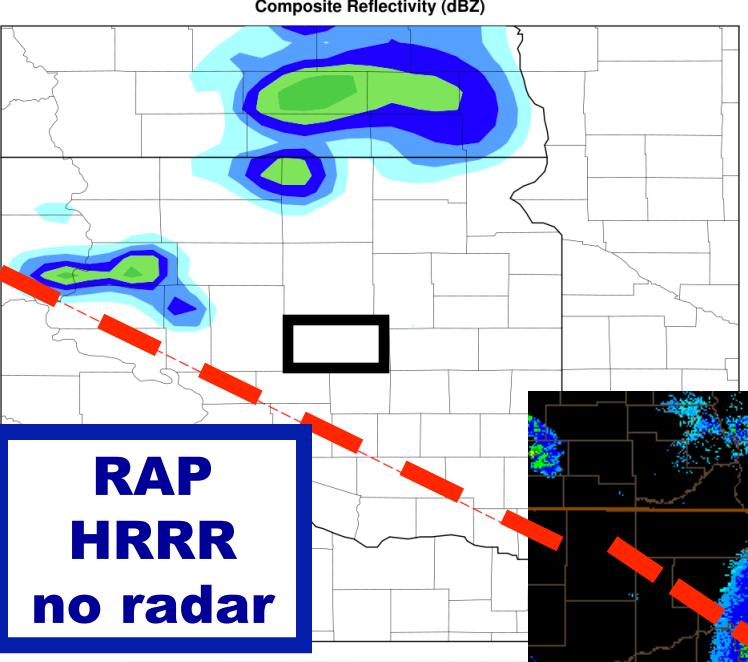
## RAP v2 improvements:

- (1) Temperature-dependent hydrometeor specification from 3D radar reflectivity (less 1h precip bias)

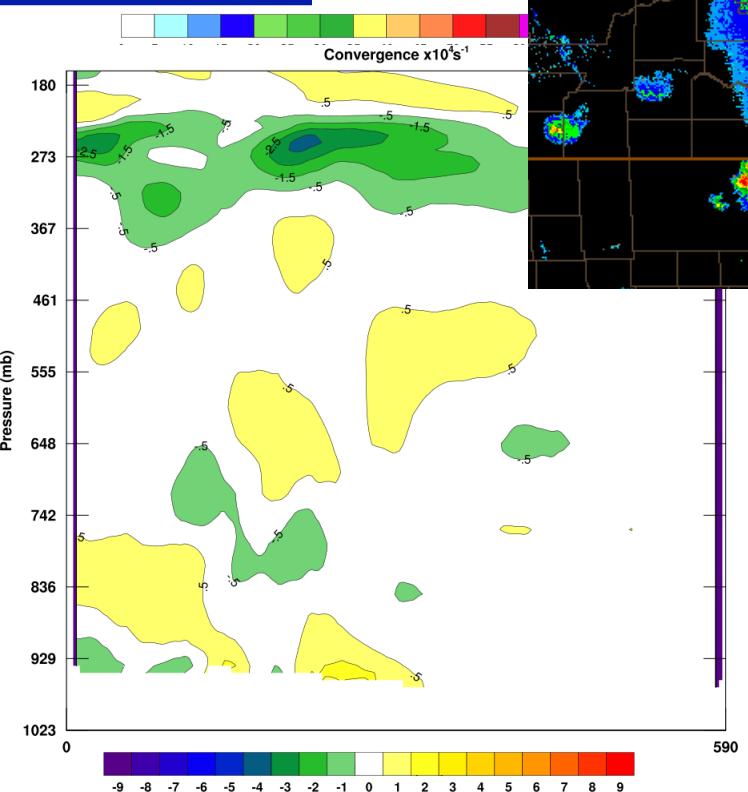
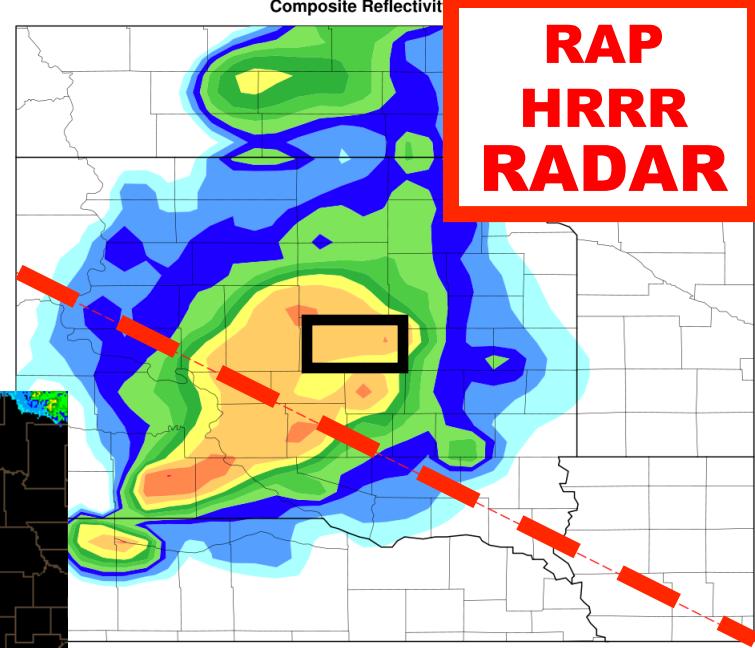
# Diabatic Digital Filter Initialization

Reduce noise in RUC and Rapid Refresh

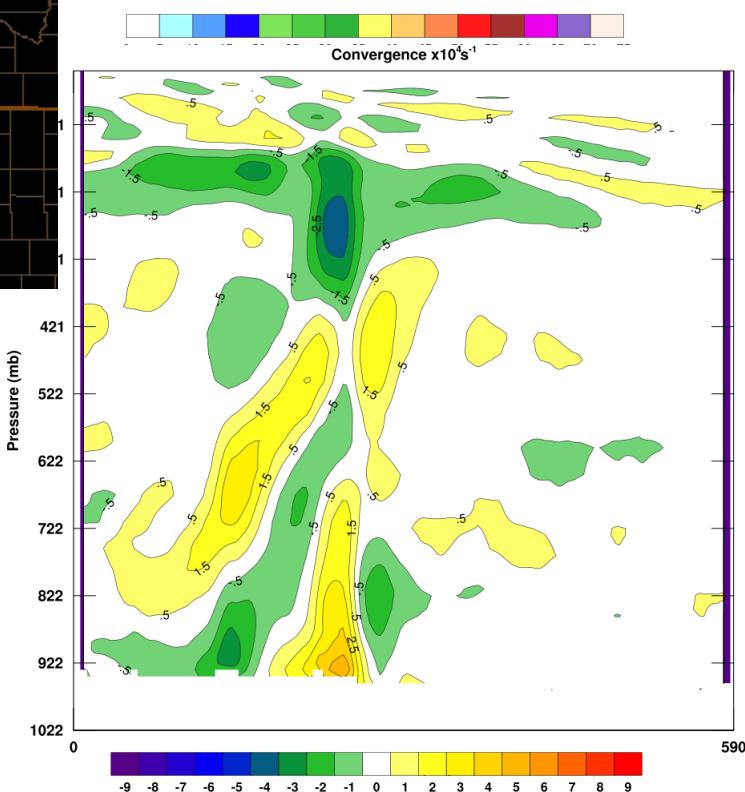


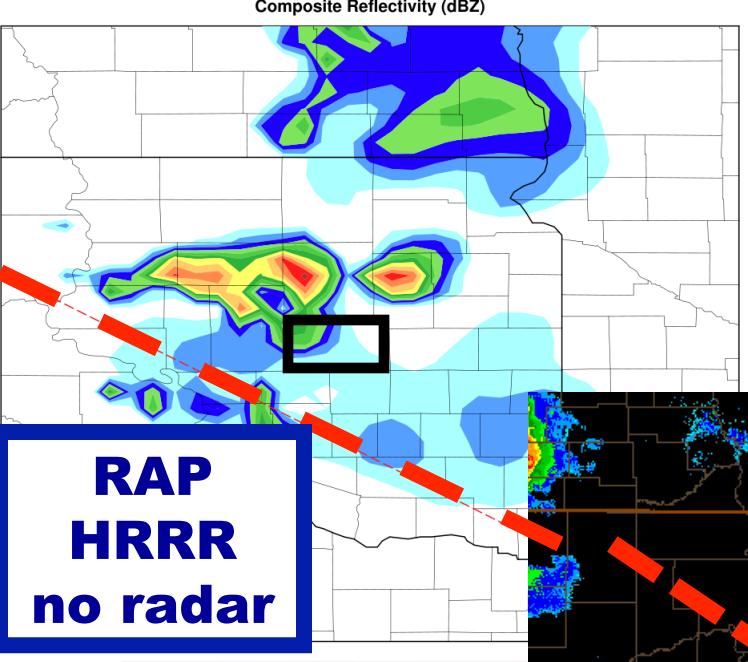


Reflectivity  
00z init  
00z 12 Aug  
2011

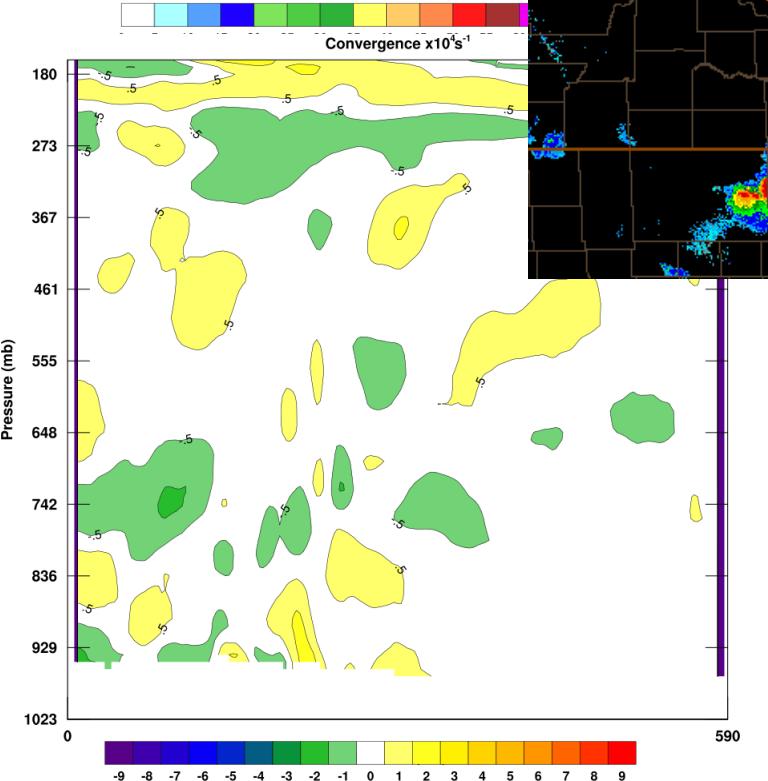
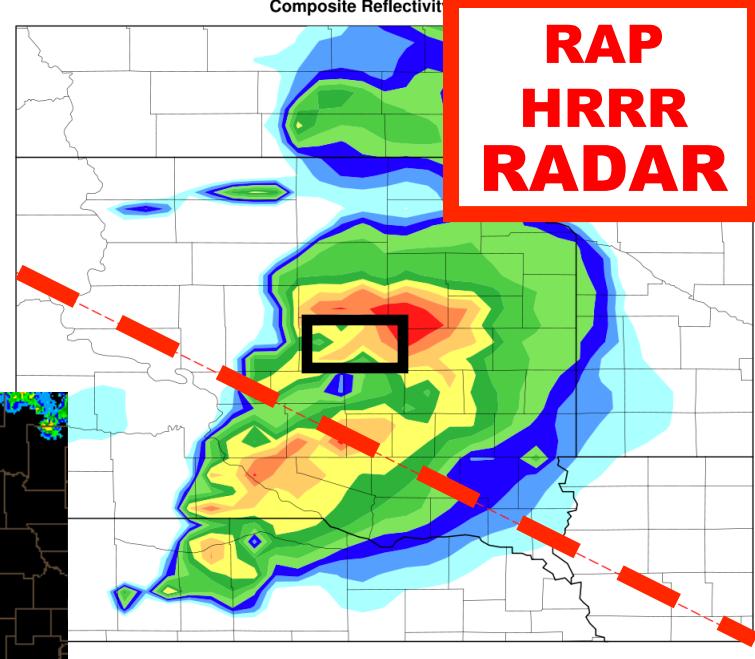


Convergence  
Cross-Section

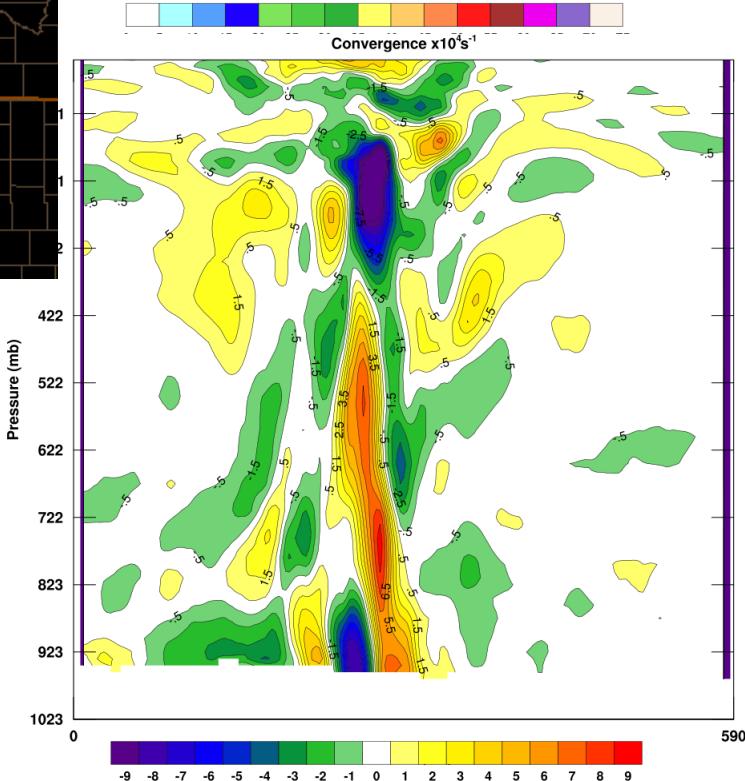




Reflectivity  
+1h fcst  
01z 12 Aug  
2011

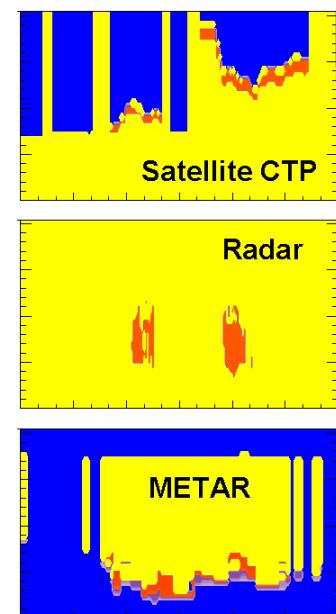
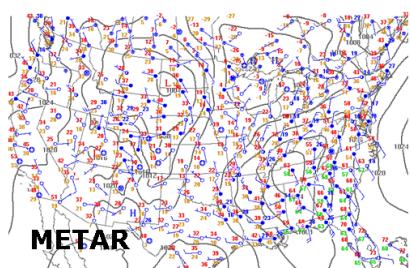
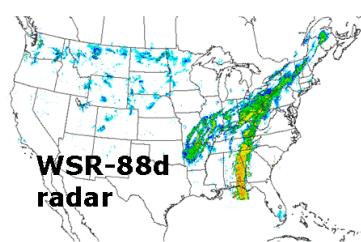
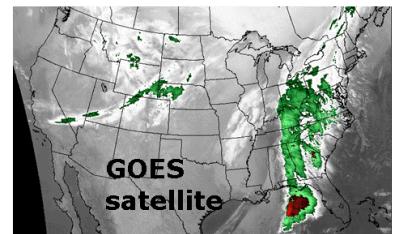


Convergence  
Cross-Section

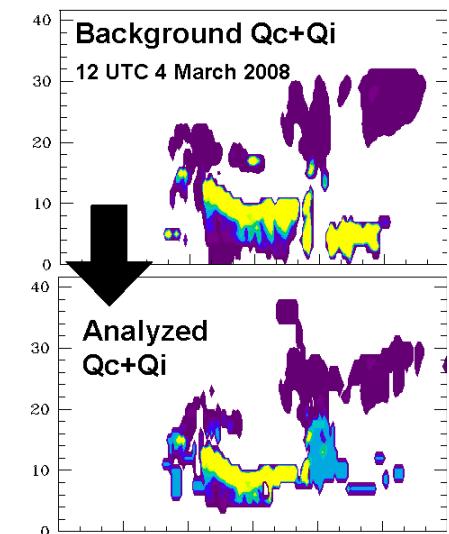
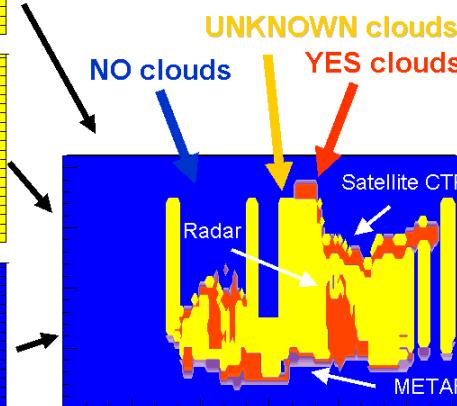


# Rapid Refresh – specific analysis features

## Cloud and hydrometeor analysis



### Cloud designation from observations

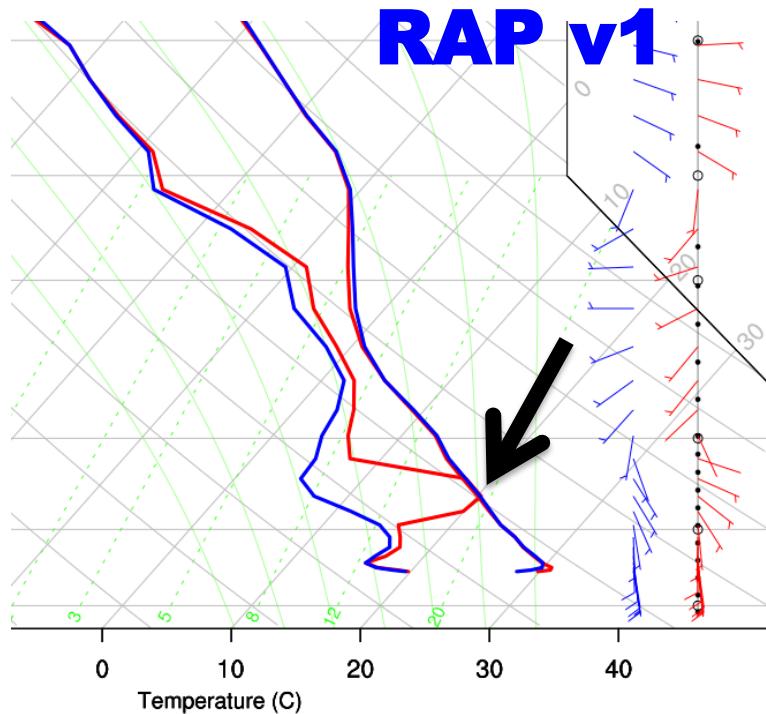


### RAP v2 improvements:

- (1) Conserve virtual potential temperature for cloud building
- (2) Building of low-level clouds from GOES data



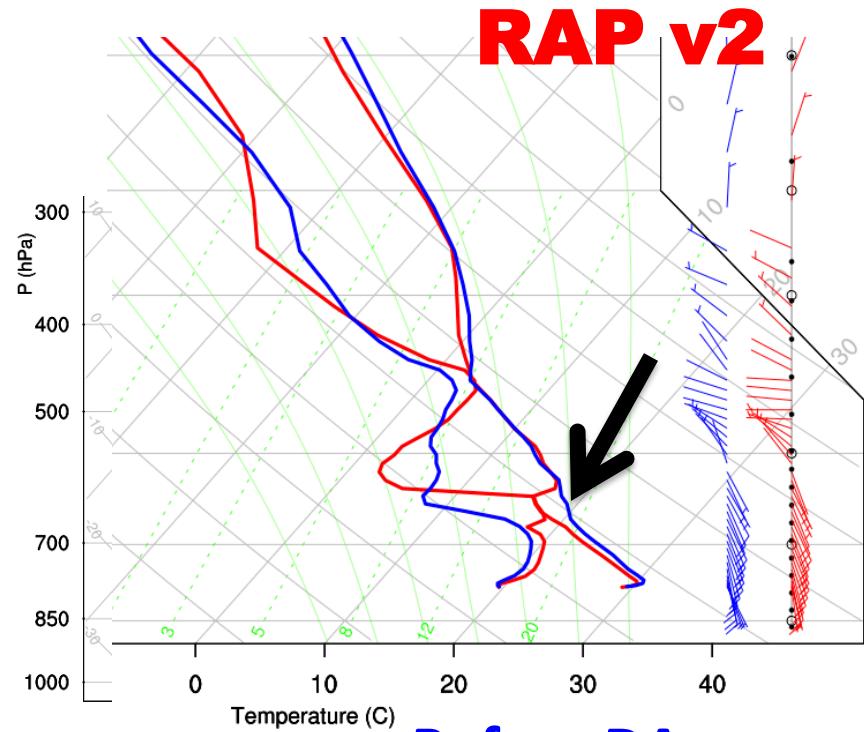
# Improved cloud analysis: assume virtual potential temperature is conserved



Before DA

After DA

**NOT conserving  $\theta_v$**



Before DA

After DA

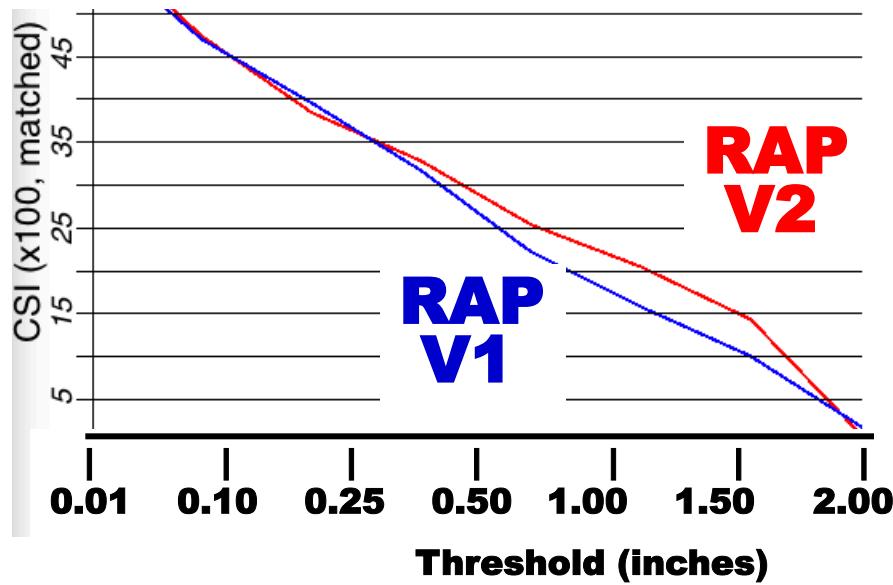
**conserving  $\theta_v$**

# RAP Precipitation Verification

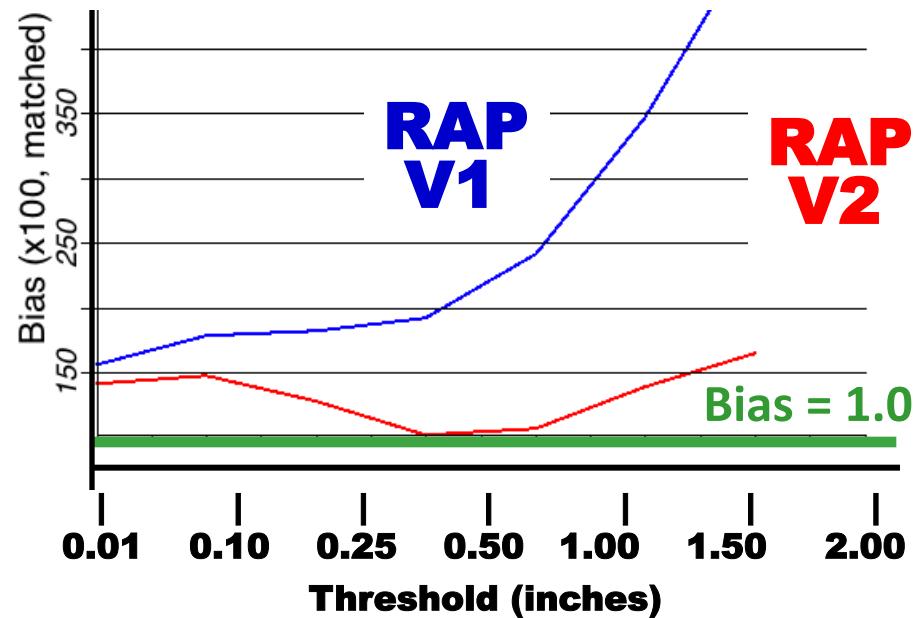
Eastern US, **8x3hr Forecasts** vs. 24h CPC

11-21 August 2011

CSI 13 km



Bias 13km

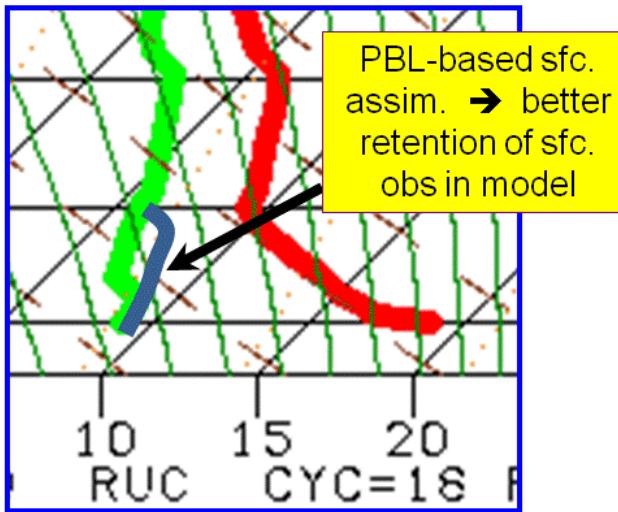
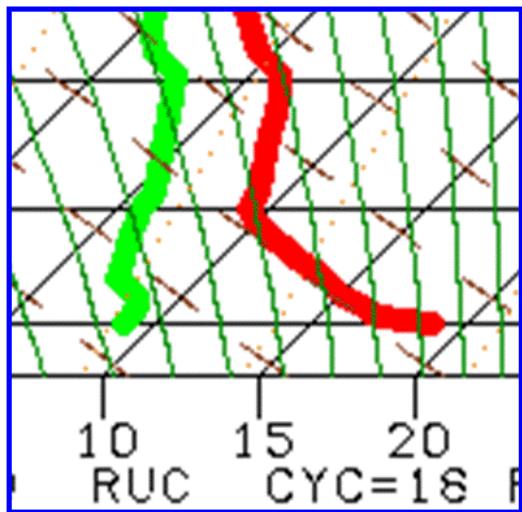


RAP version 2 has better CSI, much improved bias

# Rapid Refresh – specific analysis features

## Special treatment for surface observations

### PBL-based pseudo-observations



### RAP v2 improvements:

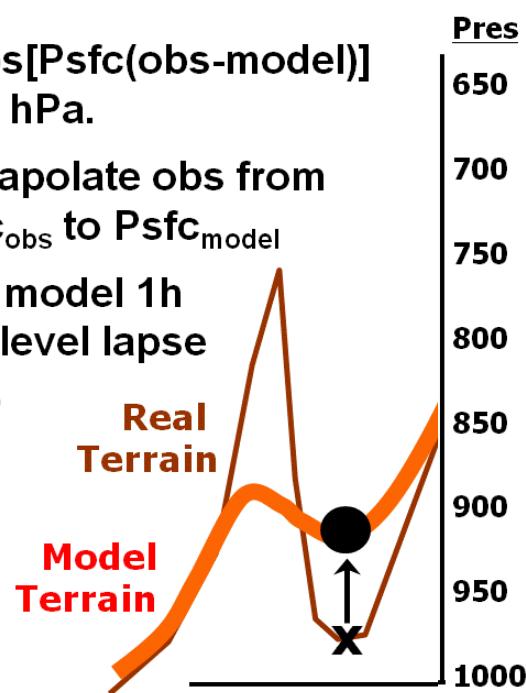
- (1) Assimilation of surface moisture pseudo-obs in PBL
- (2) Soil adjustment based on near-surface temperature / moisture increments
- (3) Elevation correction, innovation limits for PW obs

### Elevation correction

If  $\text{abs}[\text{Psfc}(\text{obs-model})] < 70 \text{ hPa}$ .

Extrapolate obs from  $\text{Psfc}_{\text{obs}}$  to  $\text{Psfc}_{\text{model}}$

Use model 1h low-level lapse rate.

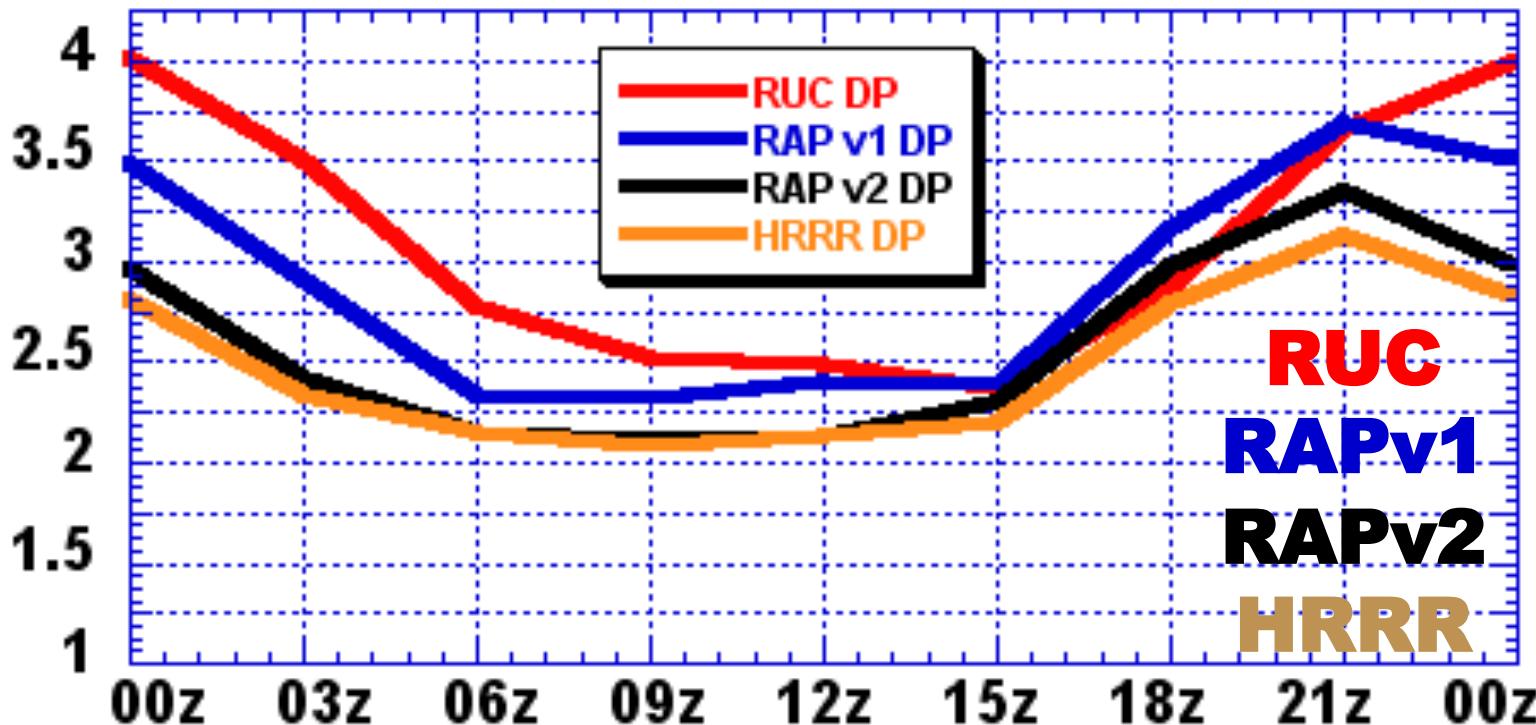


# RUC vs. RAPv1 vs. RAPv2 vs. HRRR surface dew point verification

6-h fcst dewpoint RMS diurnal variation

4-week comparison  
9 Feb – 7 Mar 2012

RMS errors:  
**RUC > RAPv1 > RAPv2 > HRRR**

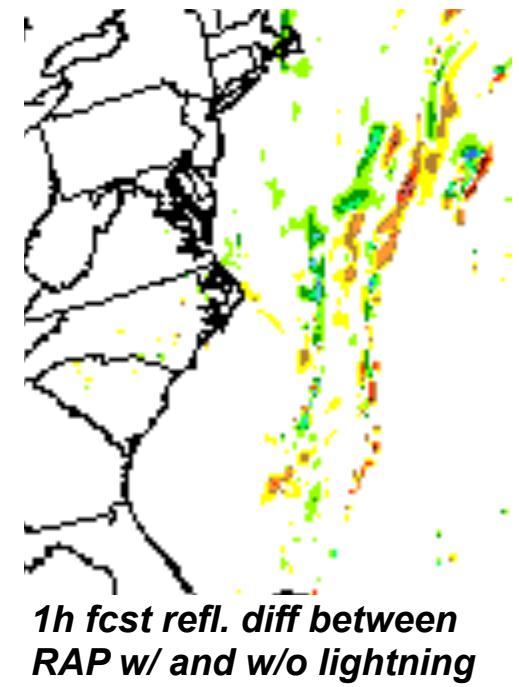
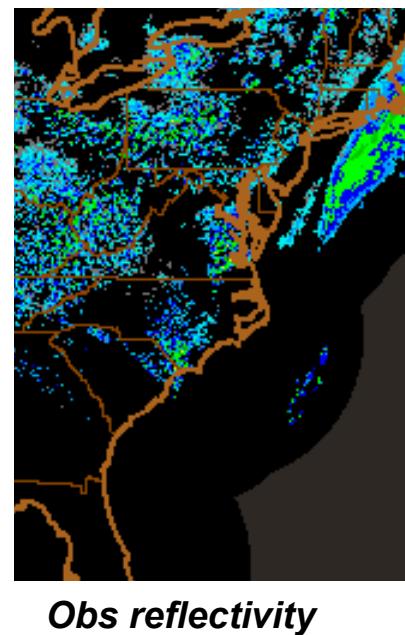
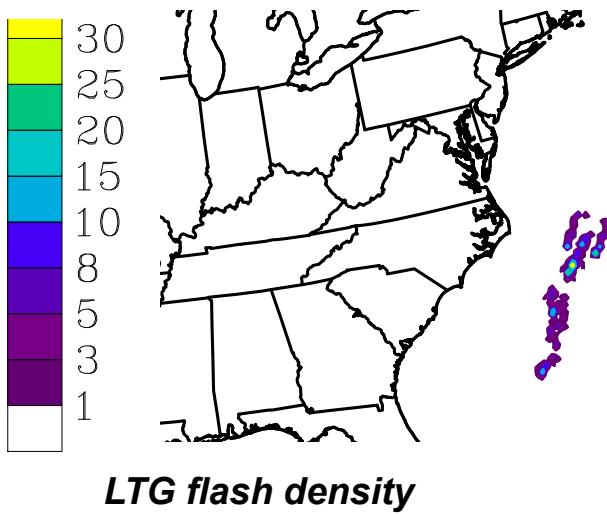




# Rapid Refresh – new observations

## RAP v2 new observation sources

- (1) Extended range lightning data (proxy for reflectivity)
- (2) Wind energy (tower, nacelle, sodar) observations
- (3) Radar radial velocity



Merge RAP GSI code with GSI code from recent NCEP/community trunk versions





# Rapid Refresh assimilation – summary

## Accurate mesoscale fields from Rapid Refresh: key aspect of HRRR success

- Use of state-of-the-art community codes (GSI, WRF)
- Hourly assimilation of conventional observations
- Use of many novel observation types and special assimilation techniques for them

**HRRR improvement strongly dependent on improvements in RAP data assimilation**

- Initial RAP (NCEP implement planned for March 20, 2012) is significant improvement over current NCEP RUC
- RAP v2 provides further significant improvement over RAP v1 (especially for moisture, precipitation)

**RAPv2 improving HRRR now, NCEP implement early 2013?**



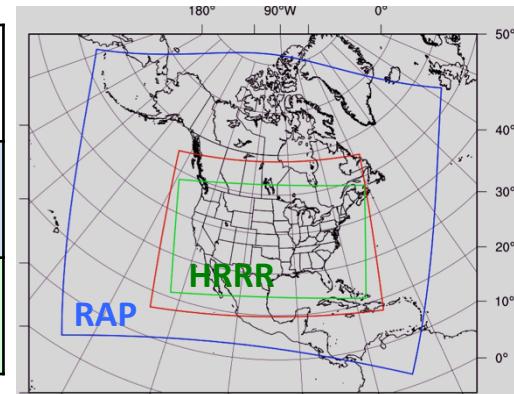
# HRRR Program Review Outline

1:30	Opening Remarks	Stan Benjamin
1:30 – 1:40	Program Overview	Curtis Alexander
1:40 – 1:50	Initial Conditions: Rapid Refresh	Steve Weygandt
1:50 – 2:00	Model Development	David Dowell
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2:20 – 2:30	Questions	



# HRRR and RAP-ESRL Model Details

Model	Domain	Grid Points	Grid Spacing	Vertical Levels	Boundary Conditions	Initialized
RAP-ESRL	North America	758 x 567	13 km	50	GFS	Hourly (cycled)
HRRR	CONUS	1799 x 1059	3 km	50	RAP-ESRL	Hourly (no-cycle)

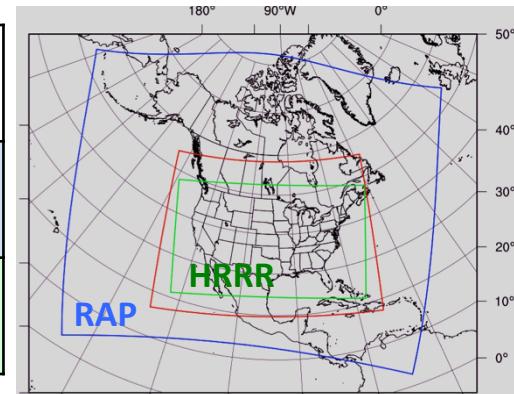


Model	Version	Assimilation	Radar DFI	Radiation	Microphysics	Cum Param	PBL	LSM
RAP-ESRL	WRF-ARW v3.3.1+	GSI-3DVar	Yes	RRTM/Goddard	Thompson v3.3.1	G3 + Shallow	MYJ	RUC v3.3.1
HRRR	WRF-ARW v3.3.1+	None: RAP I.C.	No	RRTM/Goddard	Thompson v3.3.1	None	MYJ	RUC v3.3.1



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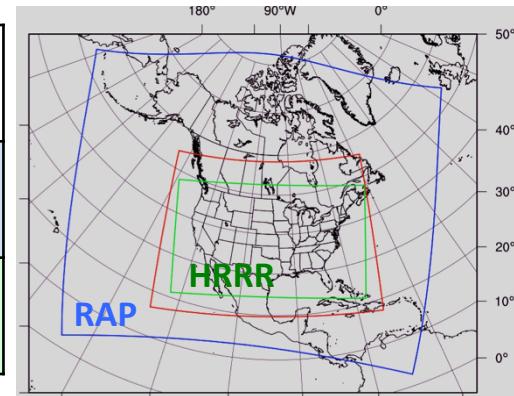


Model	Version	Assimilation	Radar DFI	Radiation	Microphysics	Cum Param	PBL	LSM
RAP-ESRL	WRF-ARW v3.3.1+	GSI-3DVar	Yes	RRTM/Goddard	Thompson v3.3.1	G3 + Shallow	MYJ	RUC v3.3.1
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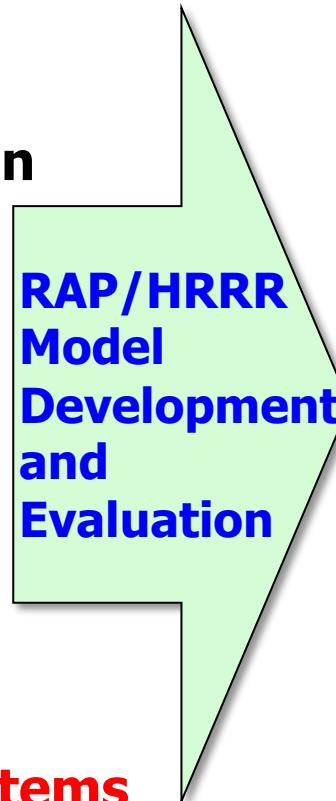
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# HRRR Forecast Behavior

2011

- (1) **High bias in convection over eastern US**
- (2) **False alarms**
- (3) **Lead in convective initiation (early AM runs)**
- (4) **Difficulty maintaining mesoscale convective systems**
- (5) **Reflectivity biases in snow and convective storms**



2012 Targets

- (1) **Lower peak bias in convection over eastern US**
- (2) **Fewer false alarms**
- (3) **Improved timing of convective initiation**
- (4) **More success maintaining mesoscale convective systems**
- (5) **More realistic reflectivity**



# RAP and HRRR Changes 2011-2012

	Model	Data Assimilation
RAP-ESRL (13 km)	<b>WRFv3.3.1+</b> <b>Physics changes</b> (convection, microphysics, land-surface, PBL) <b>Numerics changes</b> (w-damp upper bound conditions, 5 <sup>th</sup> -order vertical advection) MODIS land use, fractional 30→10 min shortwave radiation New reflectivity diagnostic	<b>Soil adjustment</b> <b>Temp-dep radar- hydrometeor building</b> <b>PW assim mods</b> <b>Cloud assim mods</b> <b>Tower/nacelle/sodar observations</b> <b>GLD360 lightning</b> <b>GSI merge with trunk</b> <b>Radial wind assim</b>
HRRR (3 km)	<b>WRFv3.3.1+</b> <b>Physics changes</b> (microphysics, land-surface, PBL) <b>Numerics changes</b> (w-damp upper bound conditions, 5 <sup>th</sup> -order vertical advection) MODIS land use, fractional 30→05 min shortwave radiation New reflectivity diagnostic	<b>3 km/15 min reflect assim</b> <b>3 km radial wind assim</b> <b>3 km cloud cycling</b> <b>3 km land-surface cycling</b>



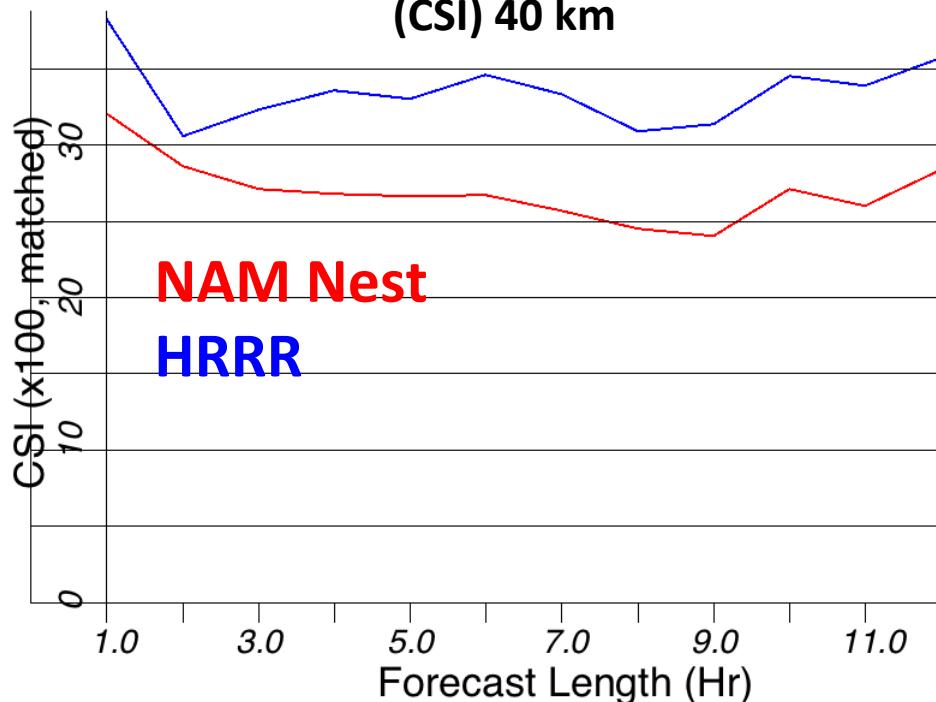
# Reflectivity Forecast Verification

Reflectivity  $\geq 25$  dBZ

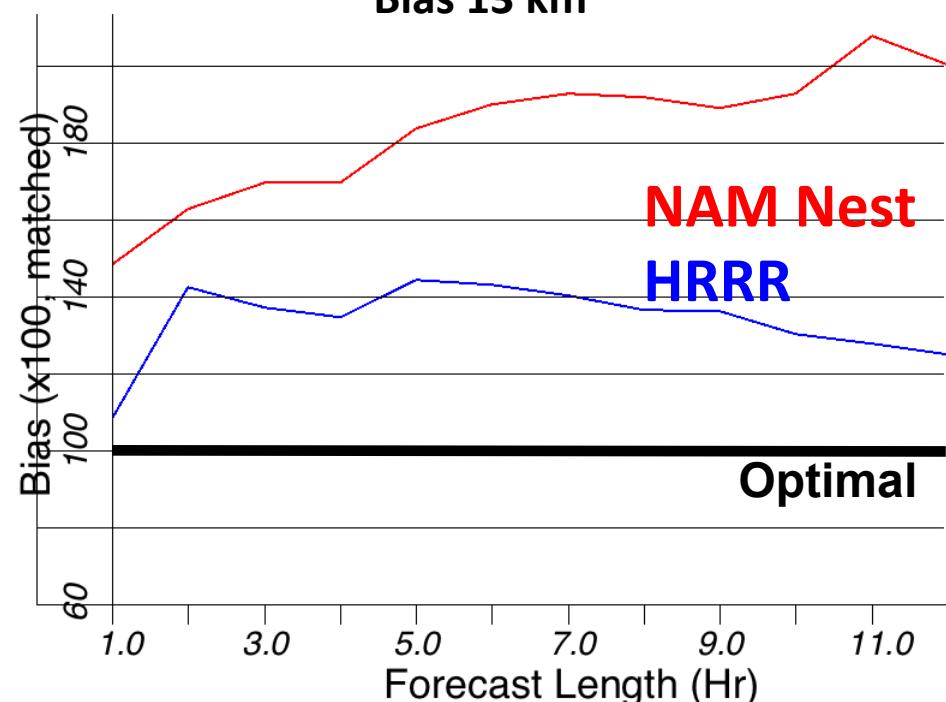
Eastern US

3 - 9 March 2012

Critical Success Index  
(CSI) 40 km



Bias 13 km



**NAM Nest:** 4-km grid spacing, CONUS, every 6 hours



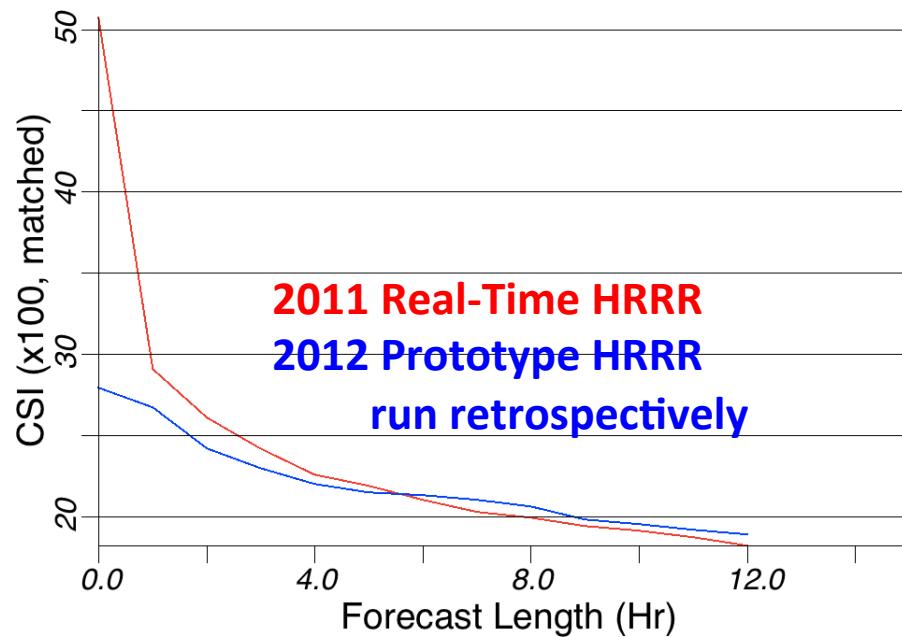
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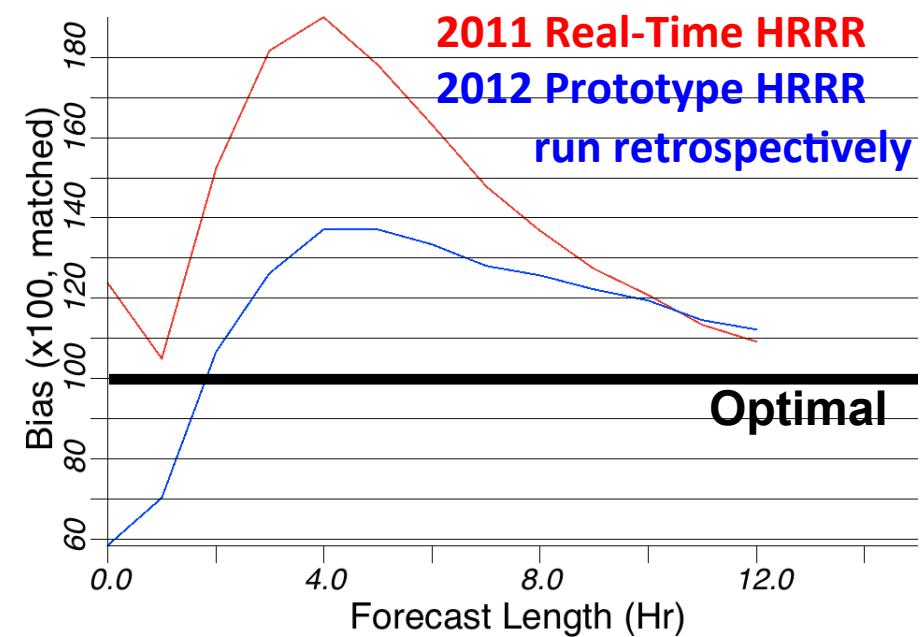
Eastern US

32 Cases from August 2011

Critical Success Index  
(CSI) 40 km



Bias 3 km

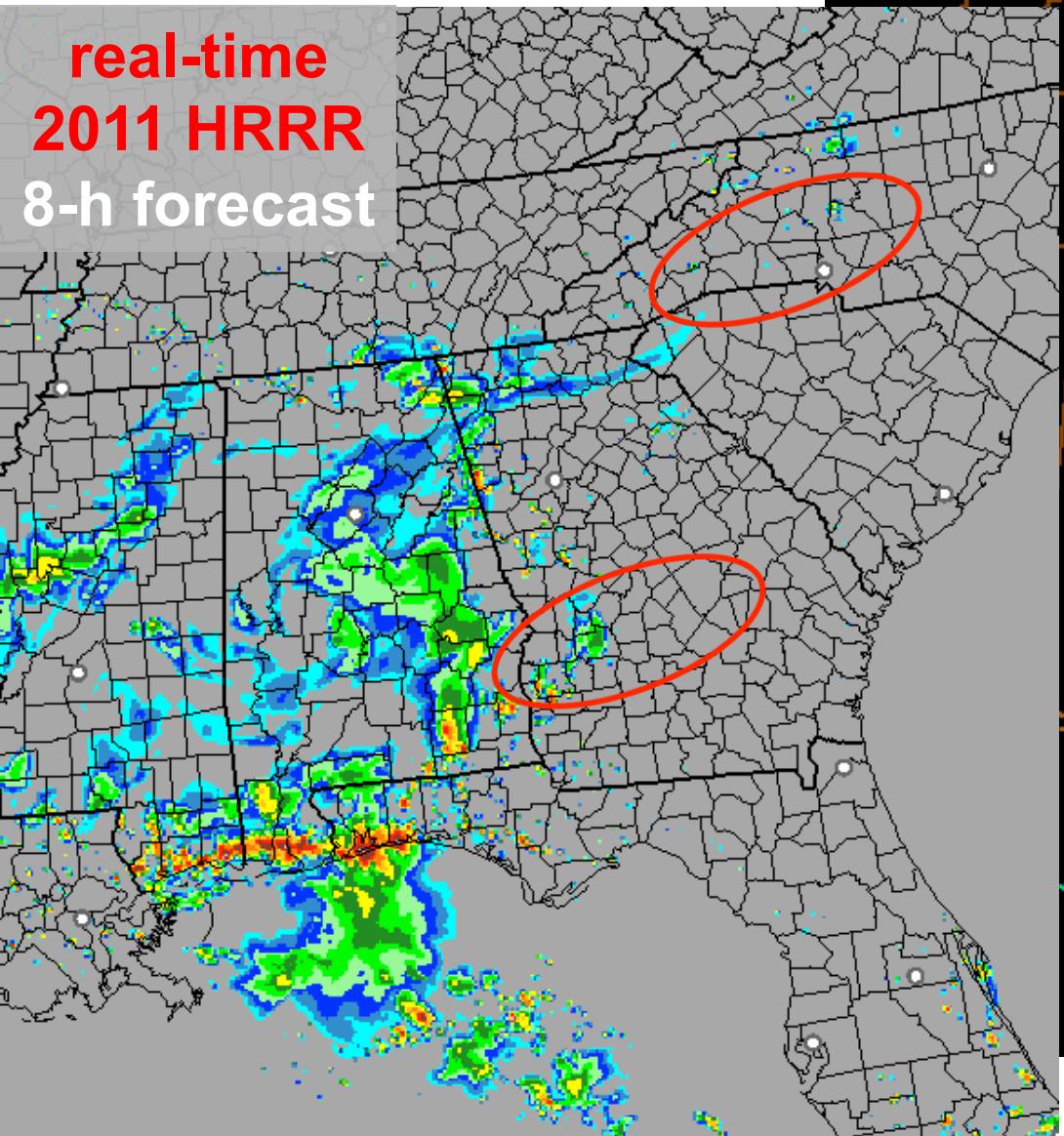


2000 UTC 11 August 2011

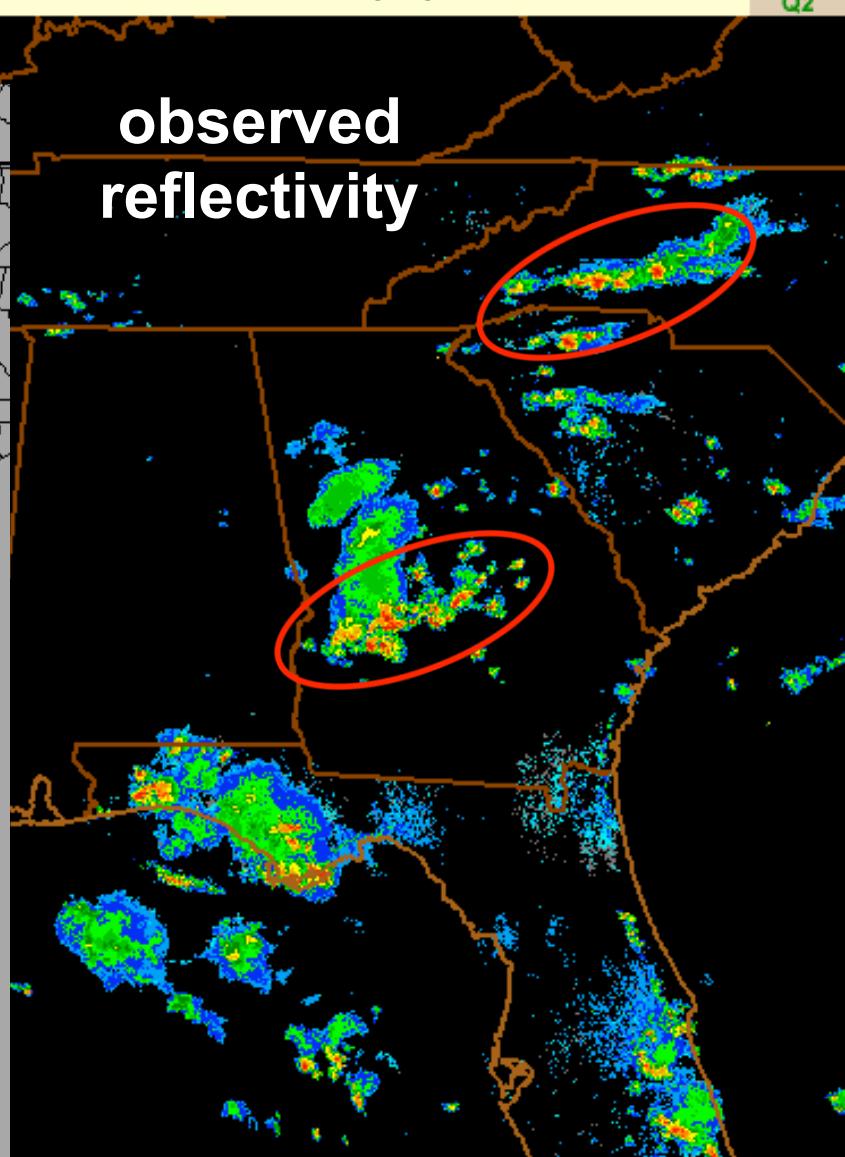
Valid At:  
08/11/2011 20:00:00 UTC



real-time  
2011 HRRR  
8-h forecast



observed  
reflectivity

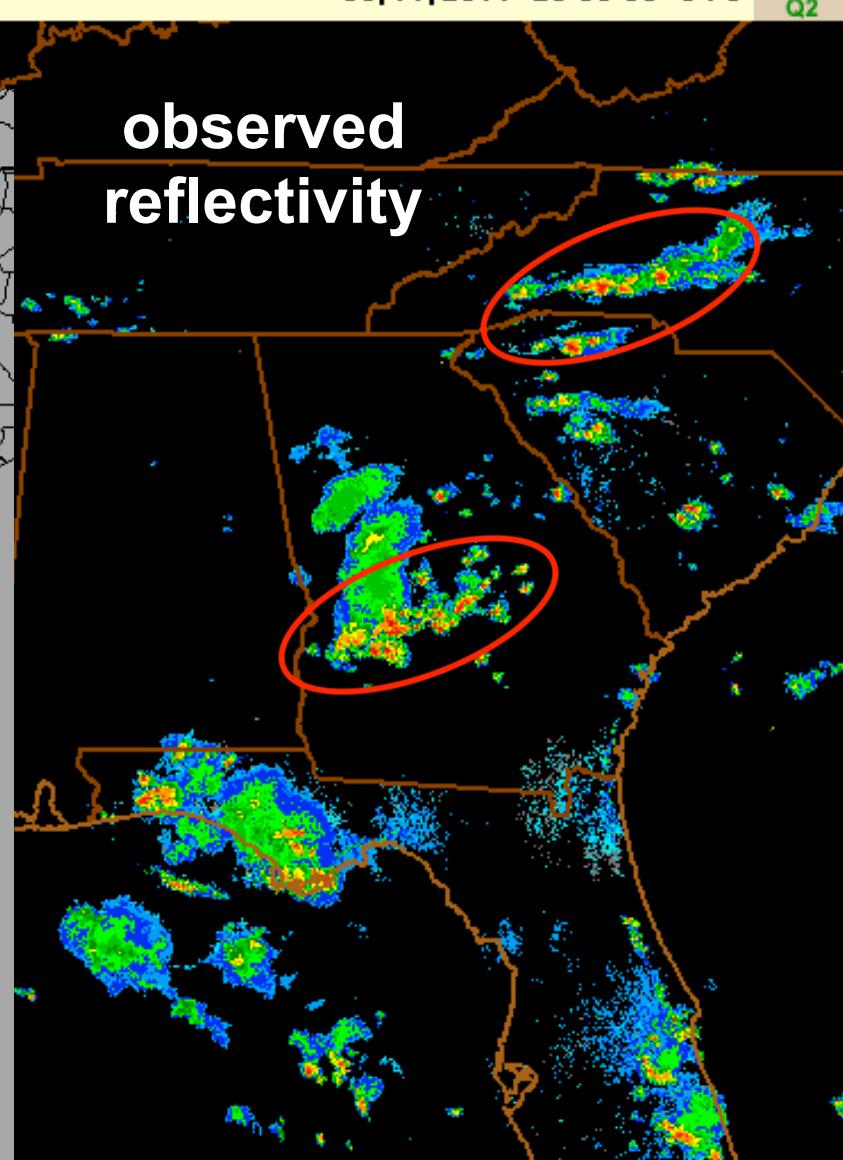
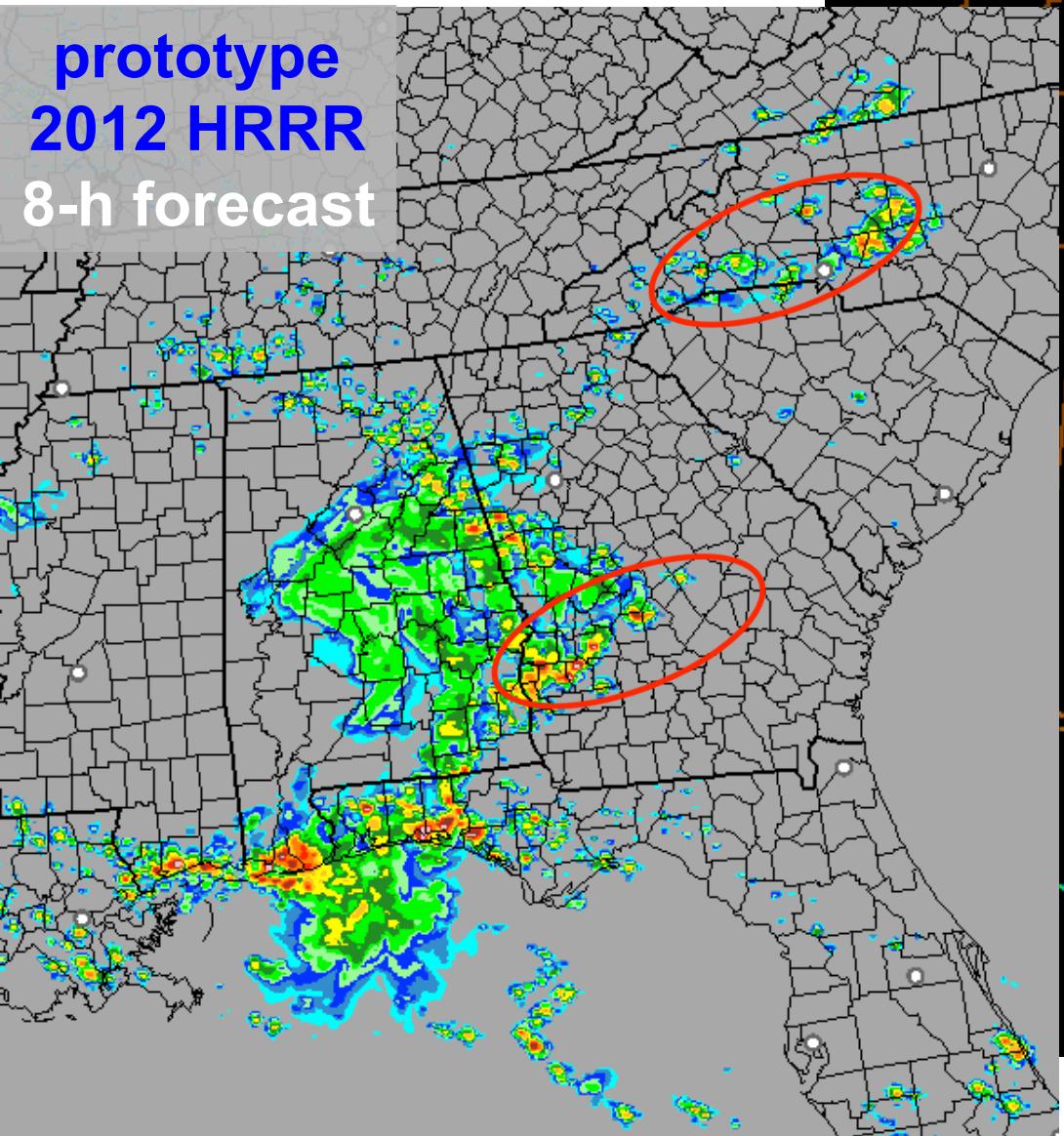


Valid At:  
08/11/2011 20:00:00 UTC



2000 UTC 11 August 2011

prototype  
2012 HRRR  
8-h forecast

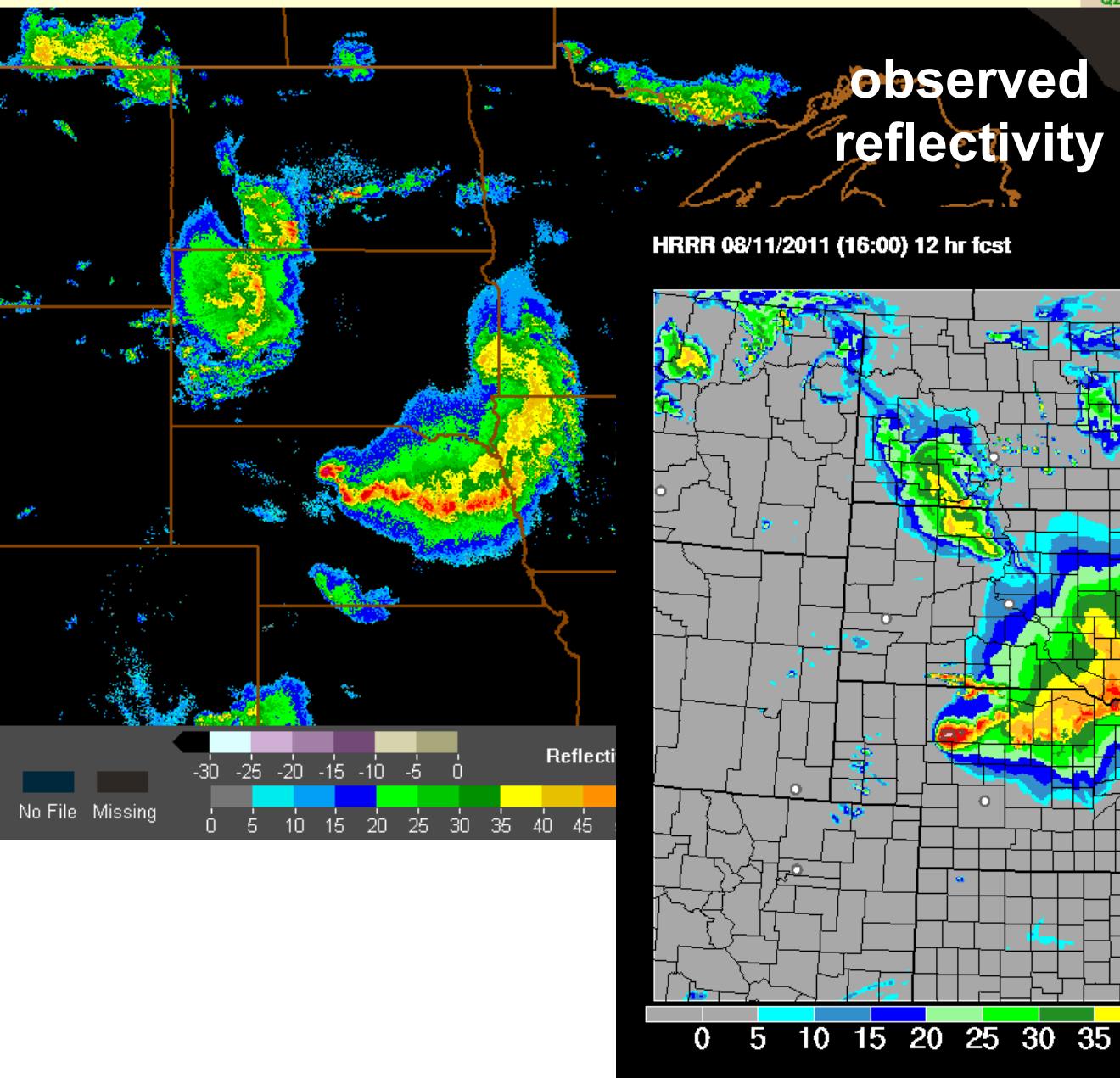


observed  
reflectivity

# Composite Reflectivity

Derived From Mosaic3D

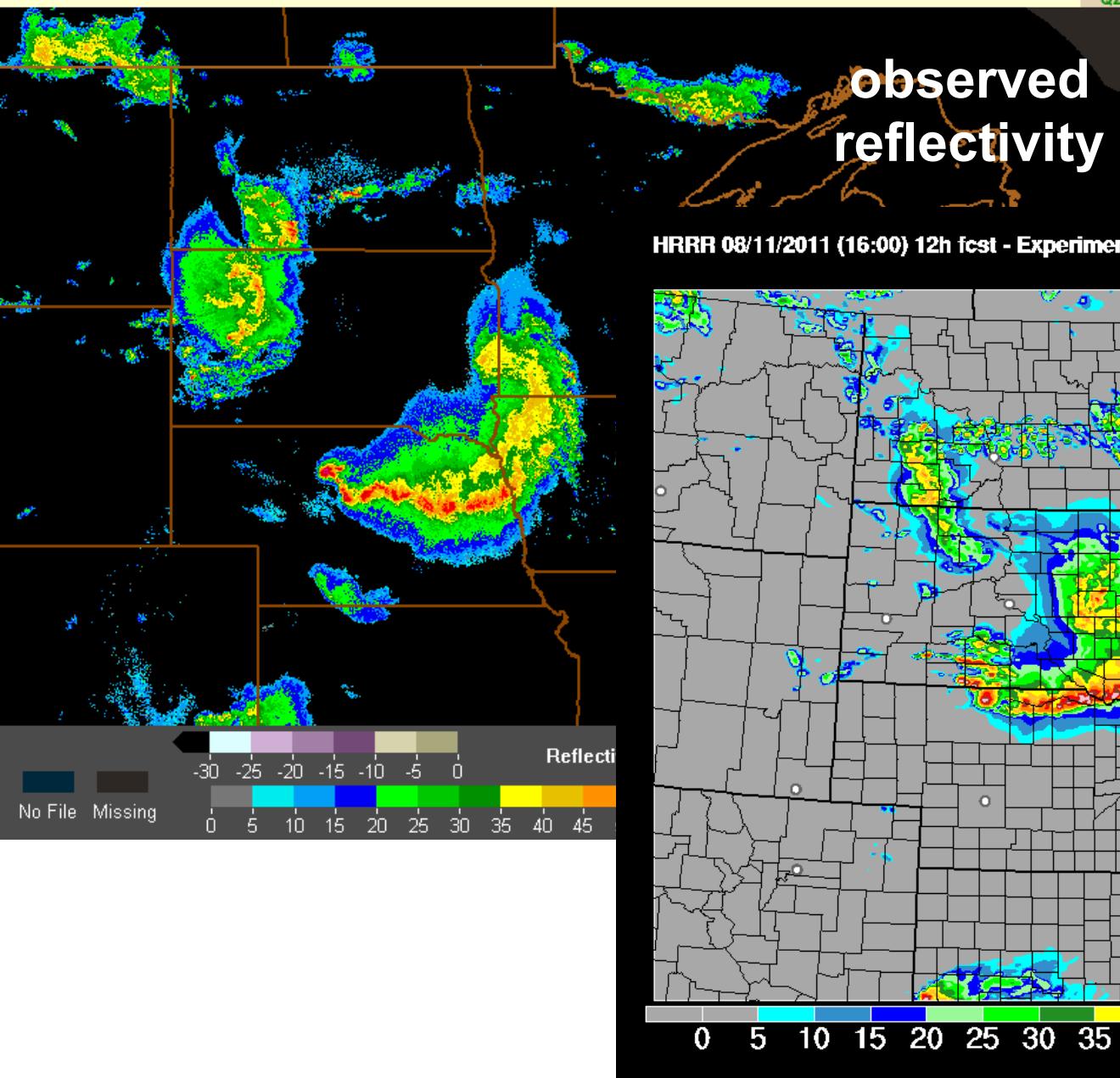
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08/12/2011 04:00:00 UTC



# Composite Reflectivity

Derived From Mosaic3D

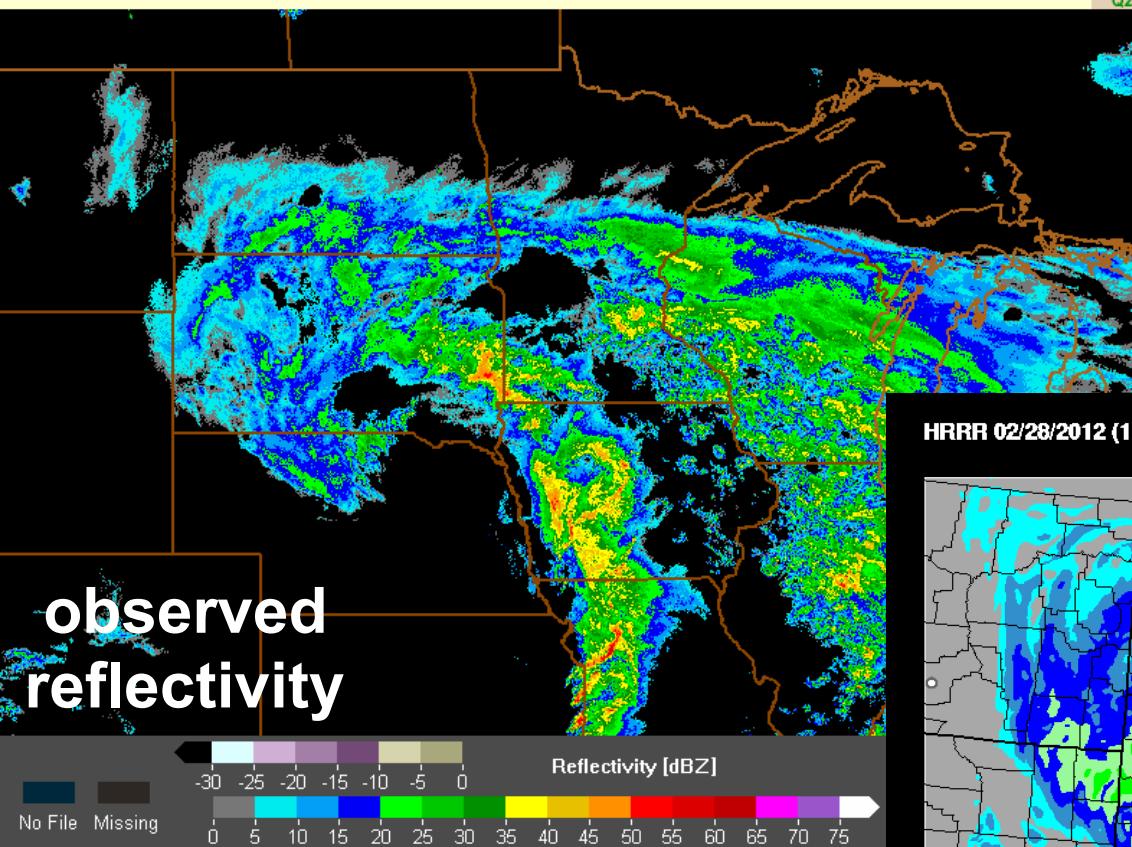
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08/12/2011 04:00:00 UTC



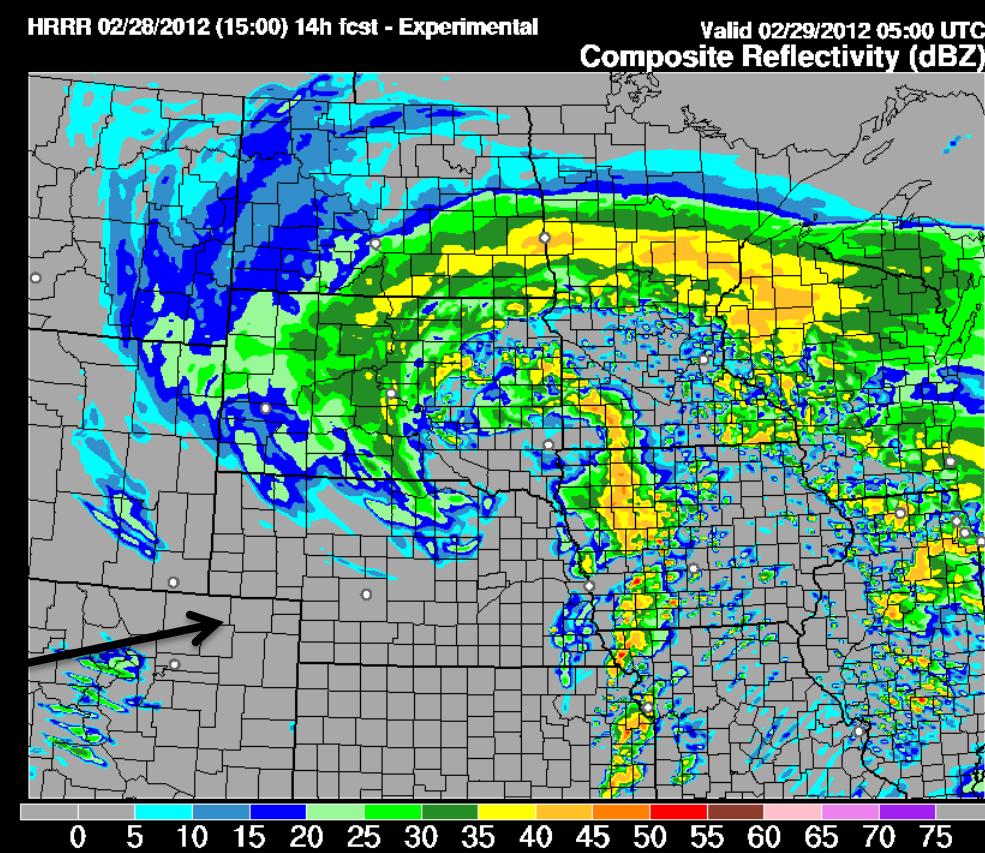
HRRR 08/11/2011 (16:00) 12h fcst - Experimental

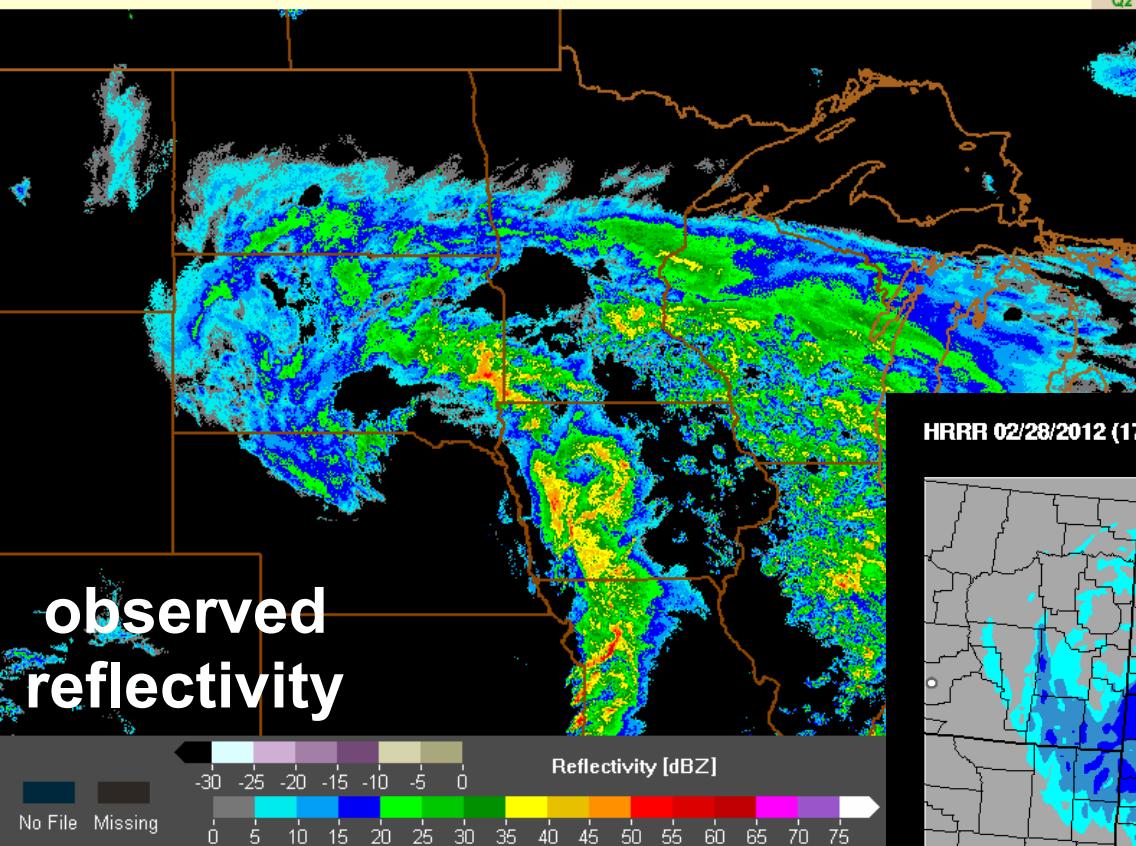
Valid 08/12/2011 04:00 UTC  
Composite Reflectivity (dBZ)

prototype  
2012 HRRR  
12-h forecast

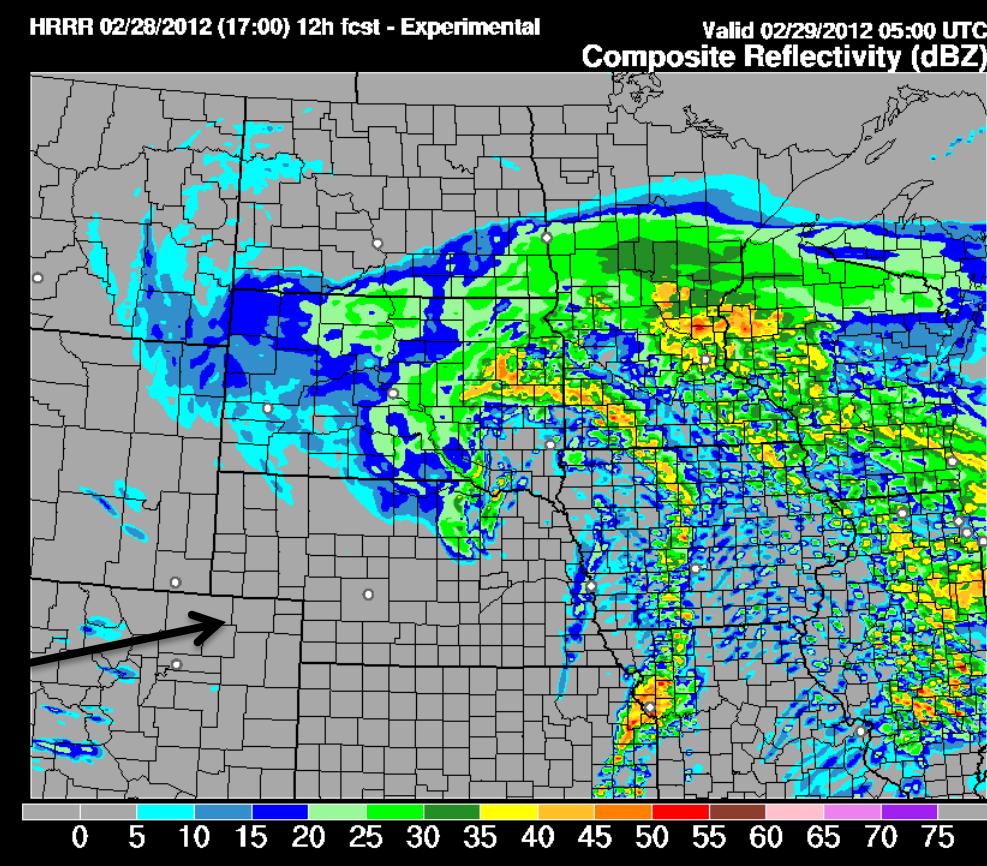


**HRRR 14-h forecast**  
initialized 1500 UTC 28 Feb 2012  
**WRF 3.2**  
**old reflectivity diagnostic**





**HRRR 12-h forecast**  
initialized 1700 UTC 28 Feb 2012  
**WRF 3.3.1**  
**new reflectivity diagnostic**



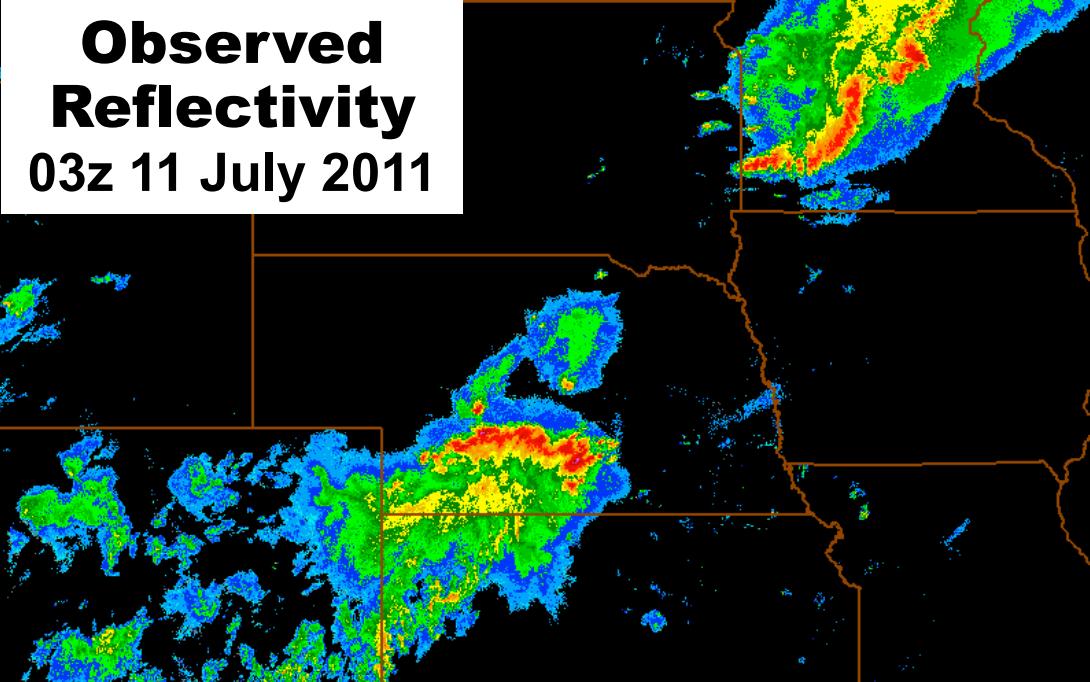


# HRRR Program Review Outline

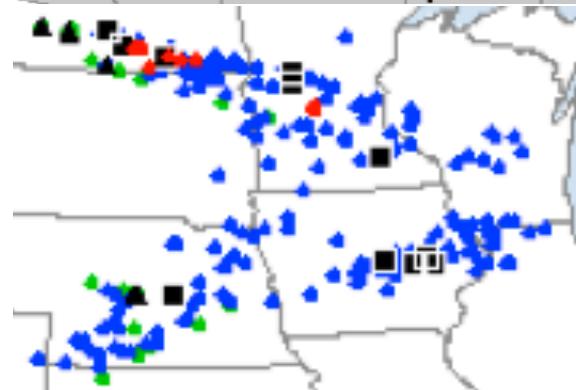
1:30	Opening Remarks	Stan Benjamin
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2:20	Summary and Future Plans	Curtis Alexander
2:20 – 2:30	Questions	

# Observed Reflectivity

03z 11 July 2011



## SPC Storm Reports

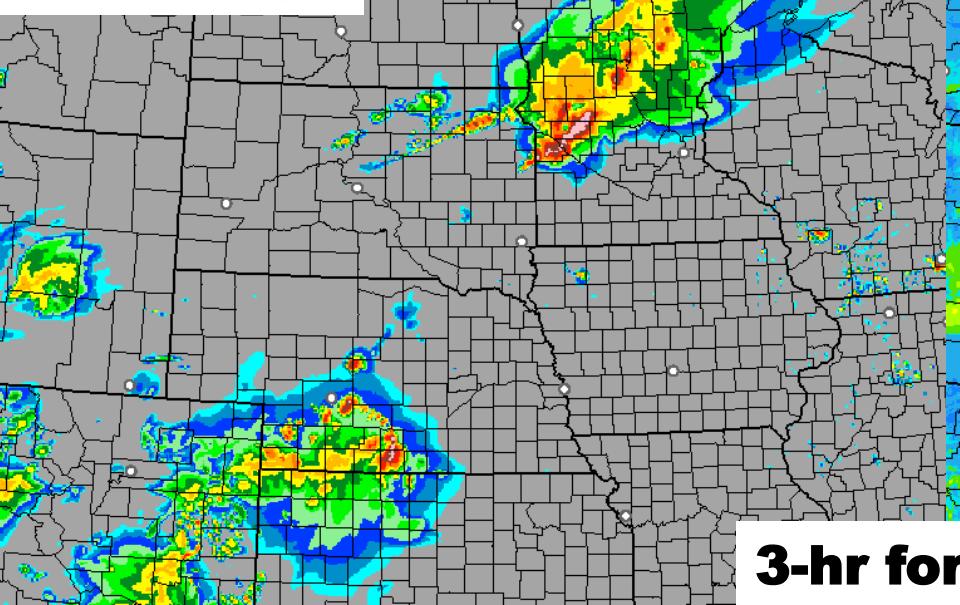


**TORNADO REPORTS.. (13)**  
**WIND REPORTS/HI.... (284/13)**  
**HAIL REPORTS/LG..... (29/6)**  
**TOTAL REPORTS..... (326)**

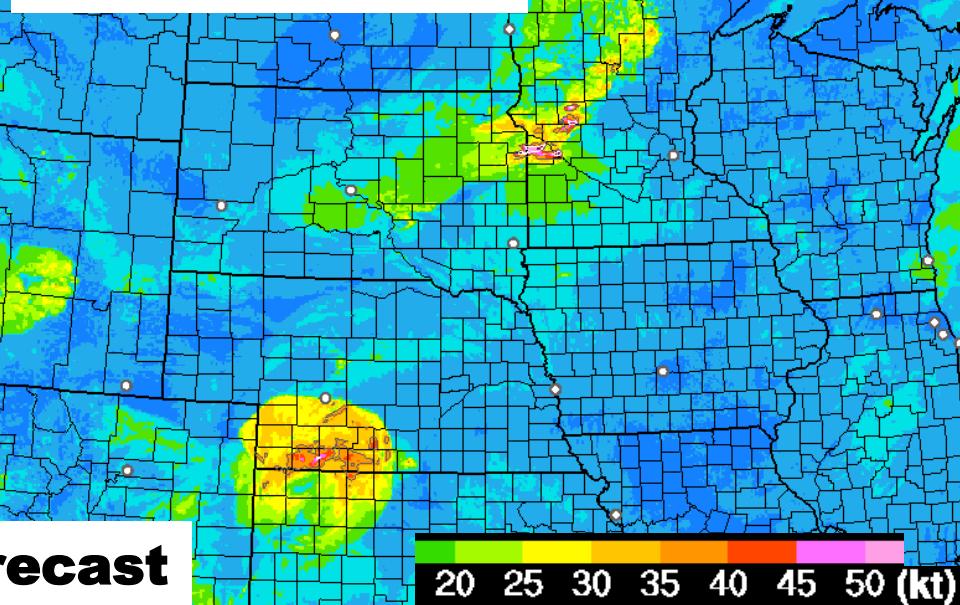
National Weather Service  
Storm Prediction Center

Norman, Oklahoma

**HRRR**  
reflectivity



**HRRR**  
1-h max 10-m wind

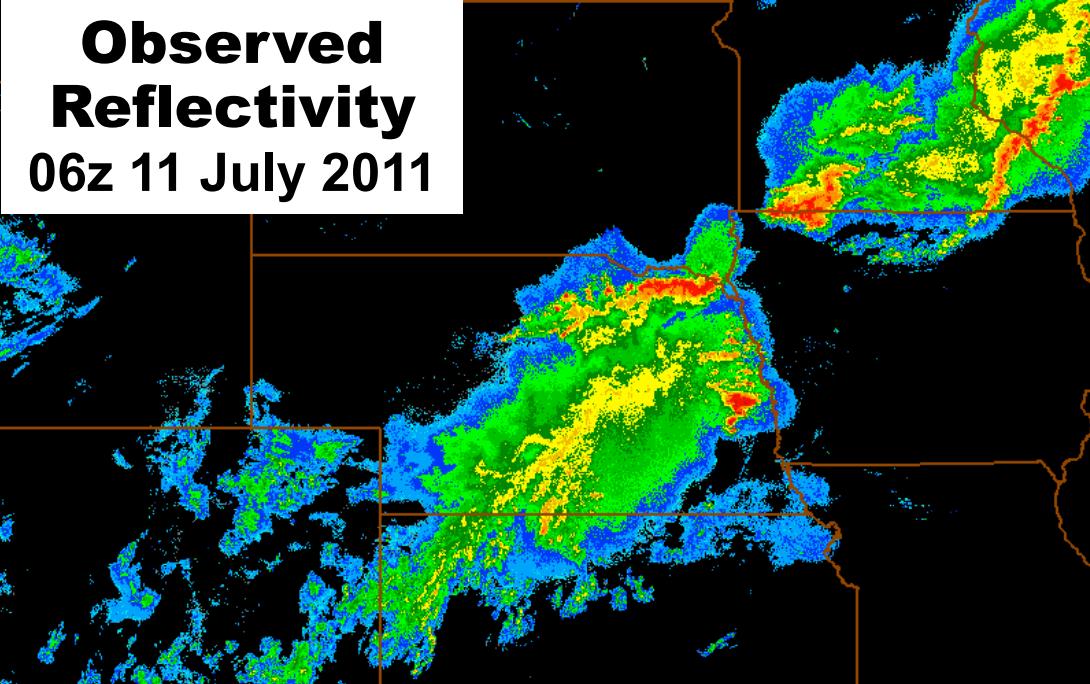


**3-hr forecast**

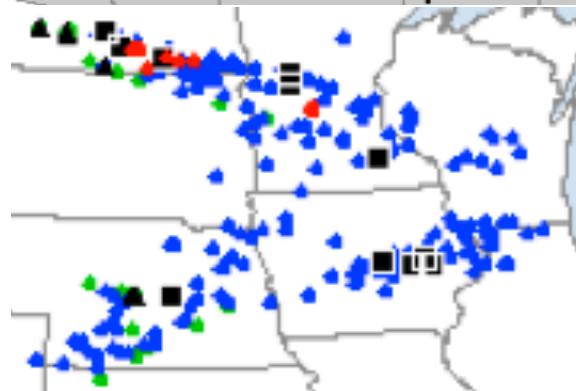
20 25 30 35 40 45 50 (kt)

# Observed Reflectivity

06z 11 July 2011



## SPC Storm Reports

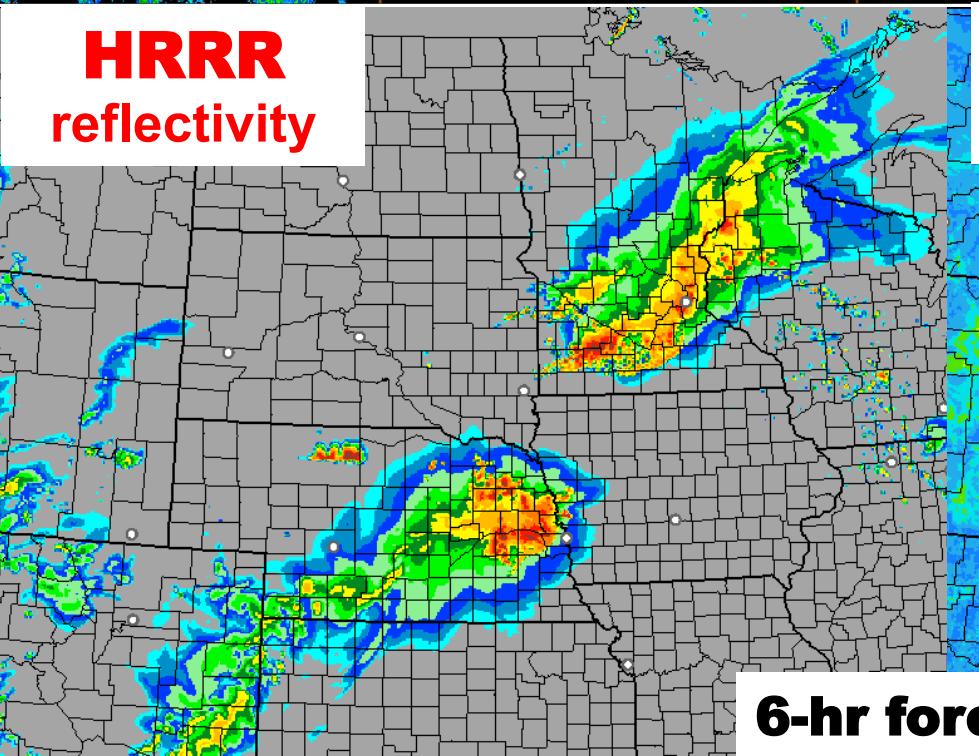


TORNADO REPORTS.. (13)  
WIND REPORTS/HI..... (284/13)  
HAIL REPORTS/LG..... (29/6)  
TOTAL REPORTS..... (326)

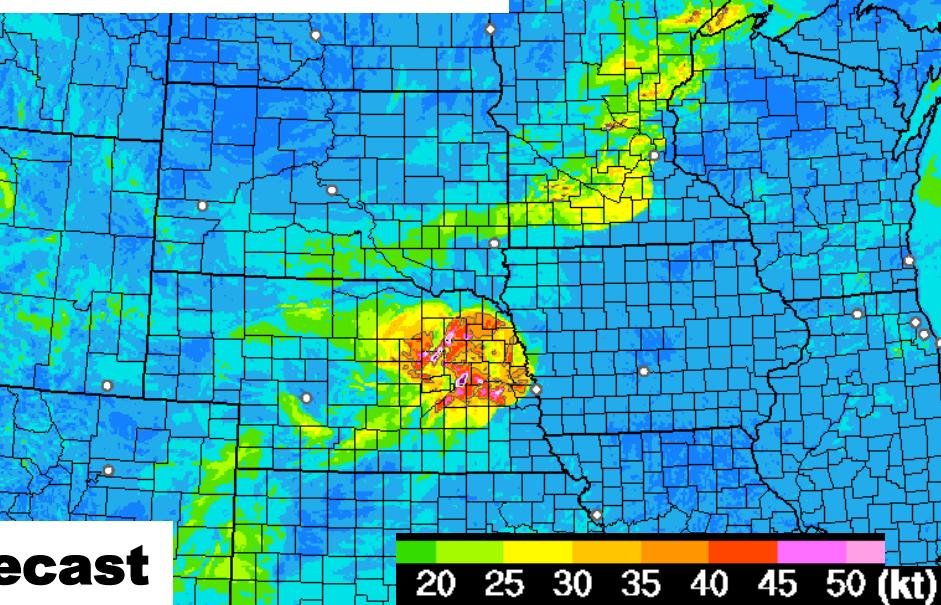
National Weather Service  
Storm Prediction Center

Norman, Oklahoma

**HRRR**  
reflectivity



**HRRR**  
1-h max 10-m wind

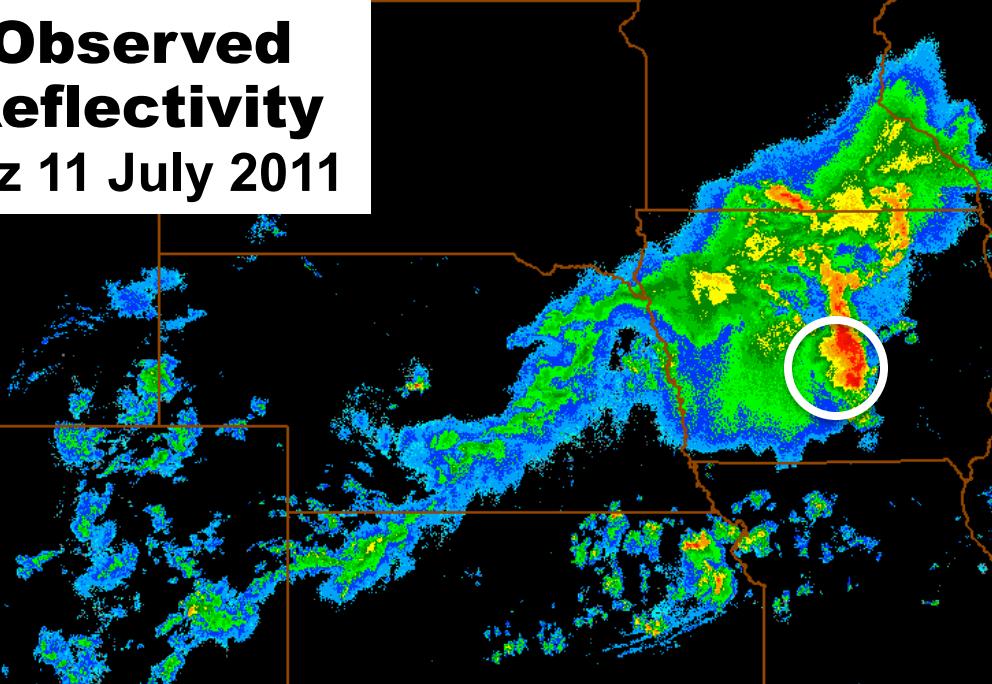


**6-hr forecast**

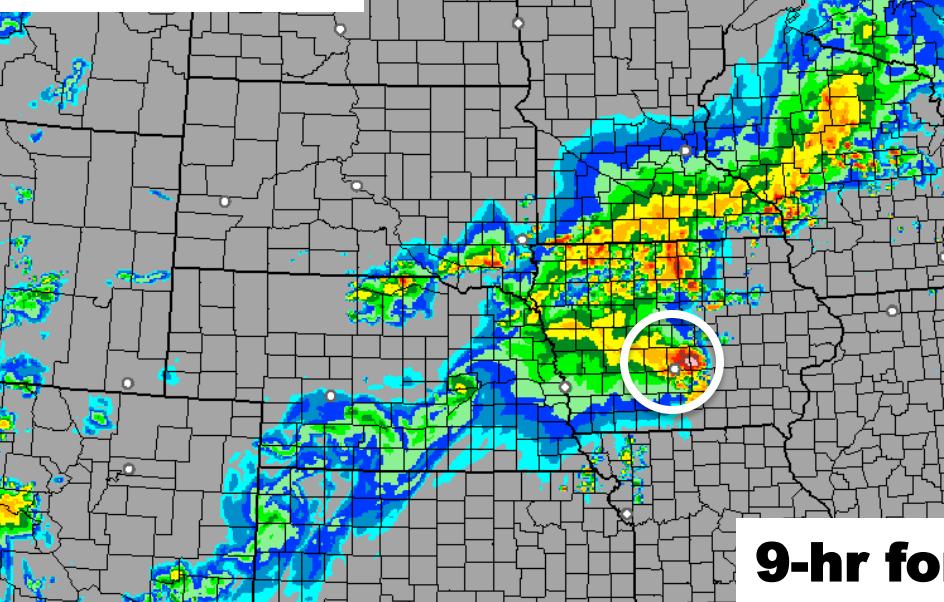
20 25 30 35 40 45 50 (kt)

# Observed Reflectivity

09z 11 July 2011

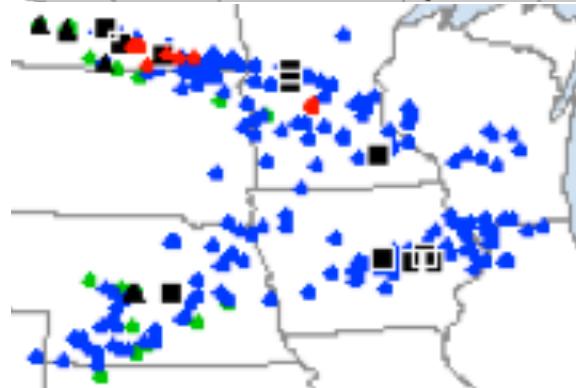


**HRRR**  
reflectivity



**9-hr forecast**

# SPC Storm Reports



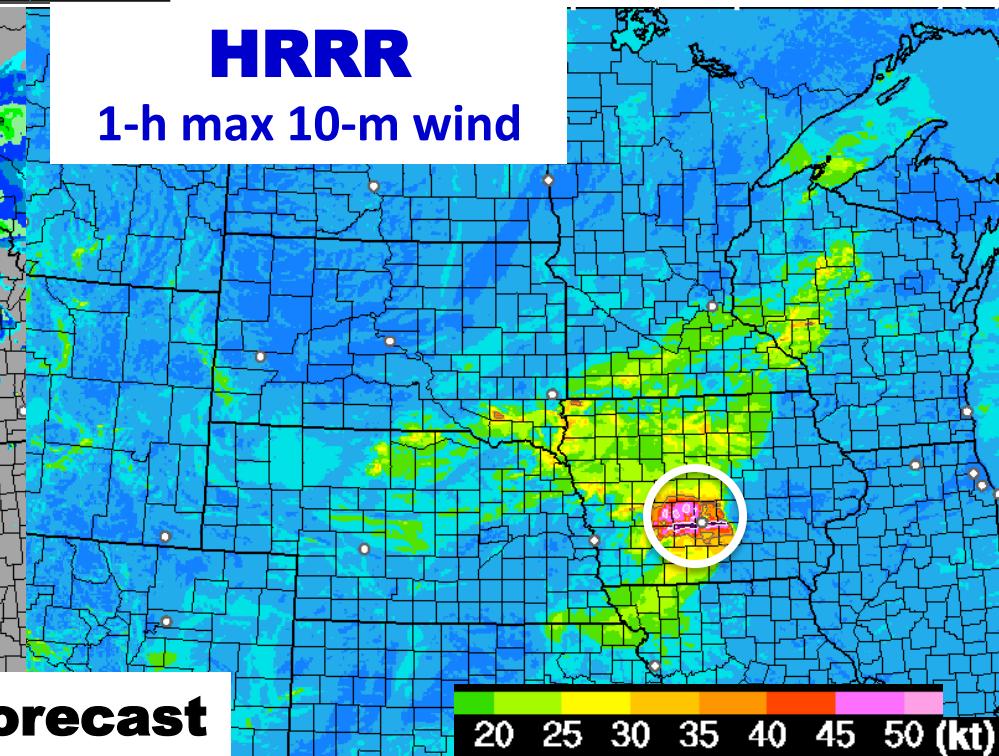
TORNADO REPORTS.. (13)  
WIND REPORTS/HI.... (284/13)  
HAIL REPORTS/LG..... (29/6)  
TOTAL REPORTS..... (326)

National Weather Service  
Storm Prediction Center

Norman, Oklahoma

**HRRR**

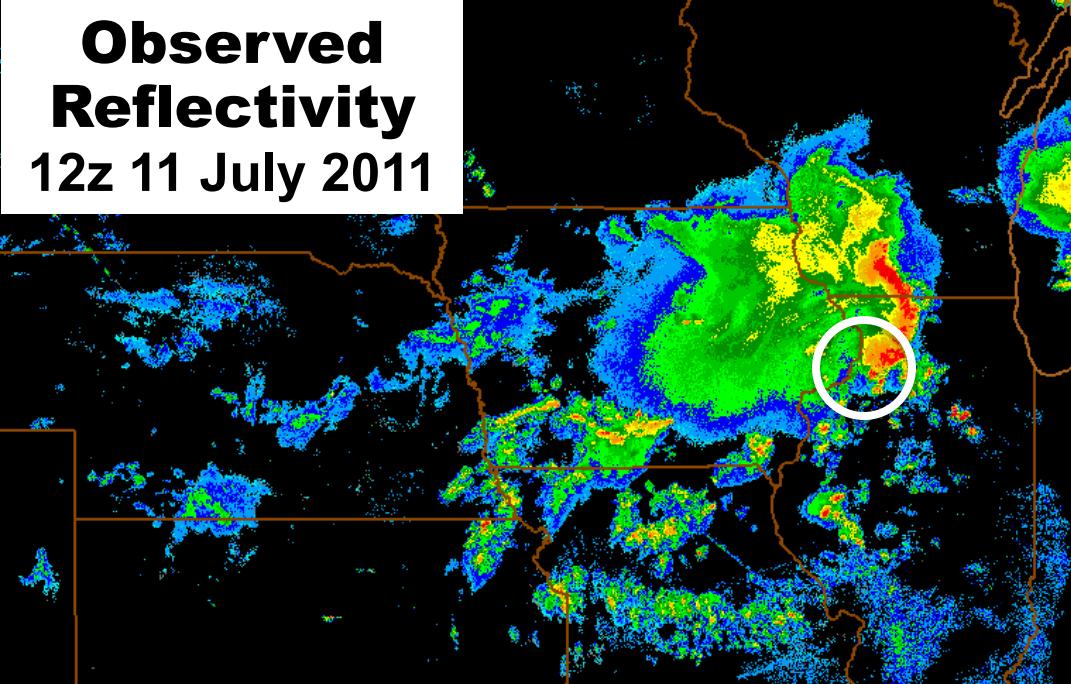
1-h max 10-m wind



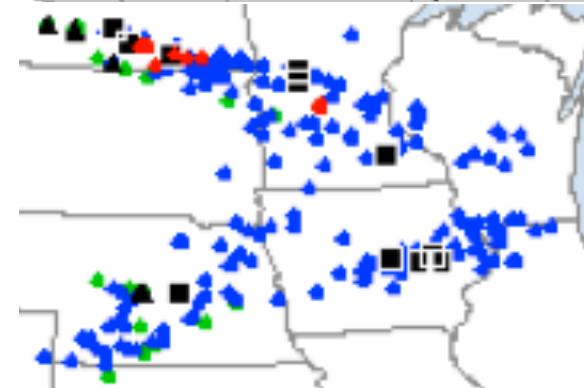
20 25 30 35 40 45 50 (kt)

# Observed Reflectivity

12z 11 July 2011



## SPC Storm Reports

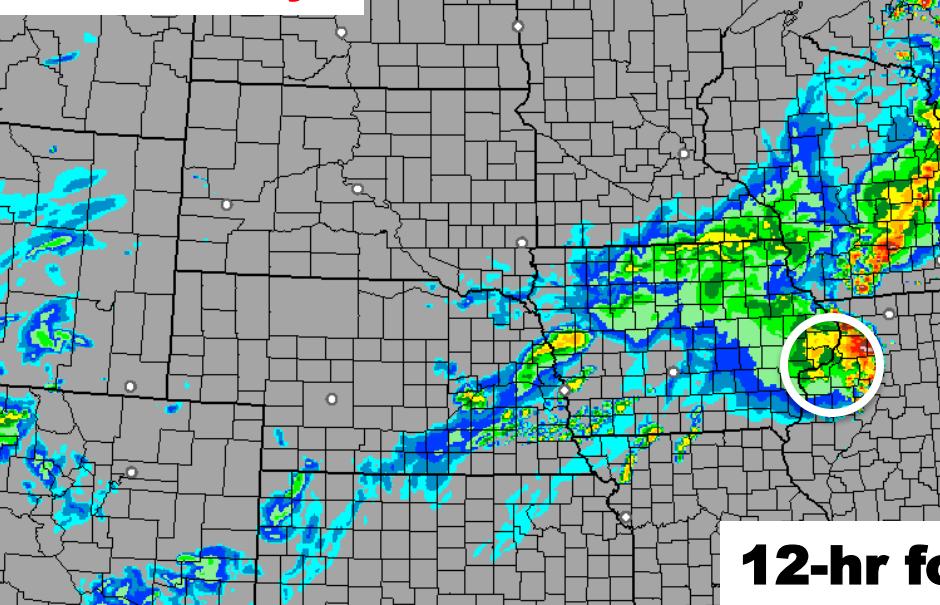


TORNADO REPORTS.. (13)  
WIND REPORTS/HI.... (284/13)  
HAIL REPORTS/LG..... (29/6)  
TOTAL REPORTS..... (326)

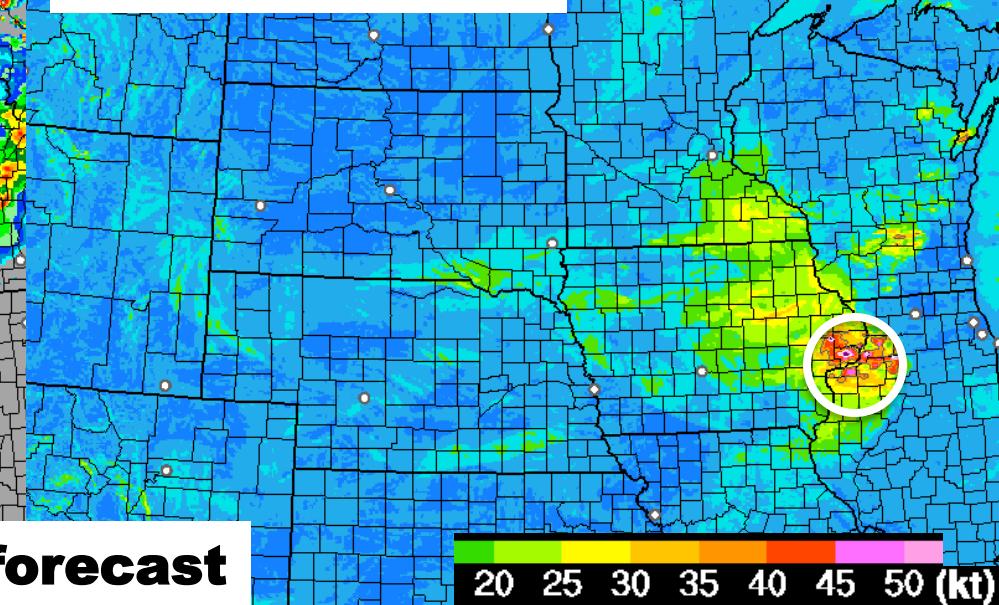
National Weather Service  
Storm Prediction Center

Norman, Oklahoma

**HRRR**  
reflectivity



**HRRR**  
1-h max 10-m wind

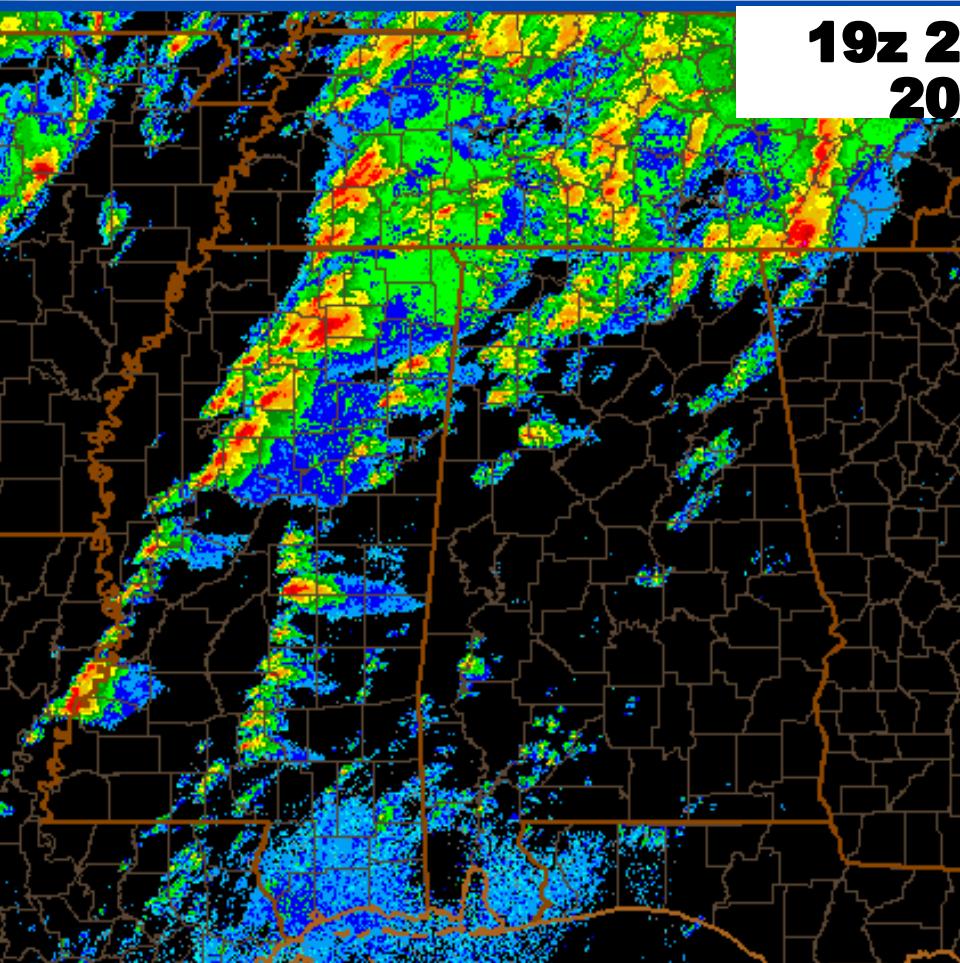


**12-hr forecast**

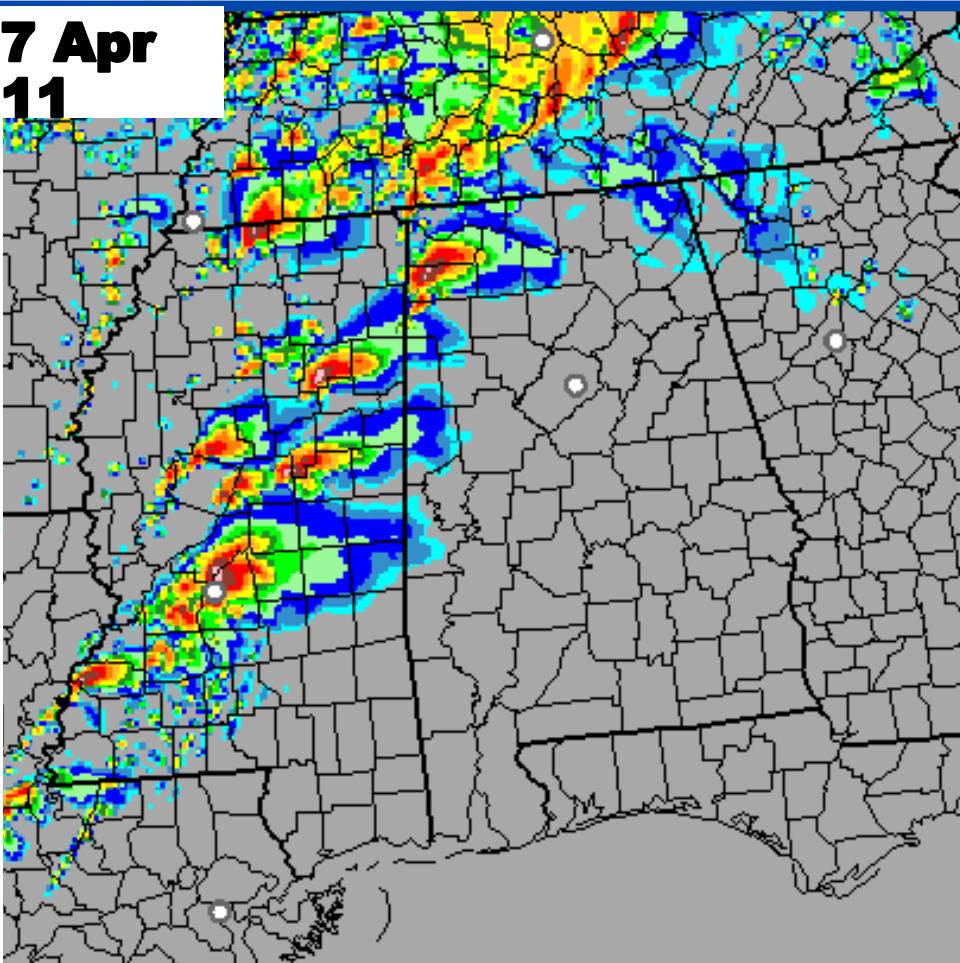
20 25 30 35 40 45 50 (kt)



# HRRR Case Studies



**NSSL  
mosaic**

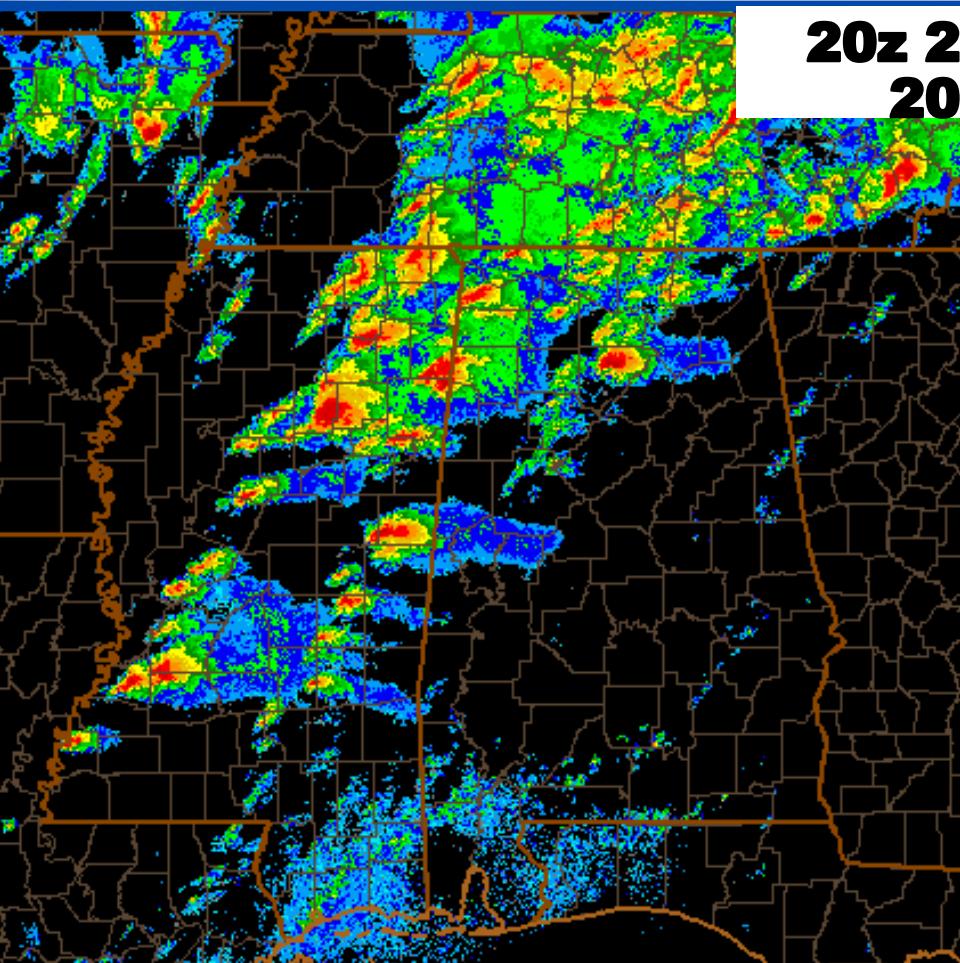


**HRRR**

**13z + 6 hr fcst**

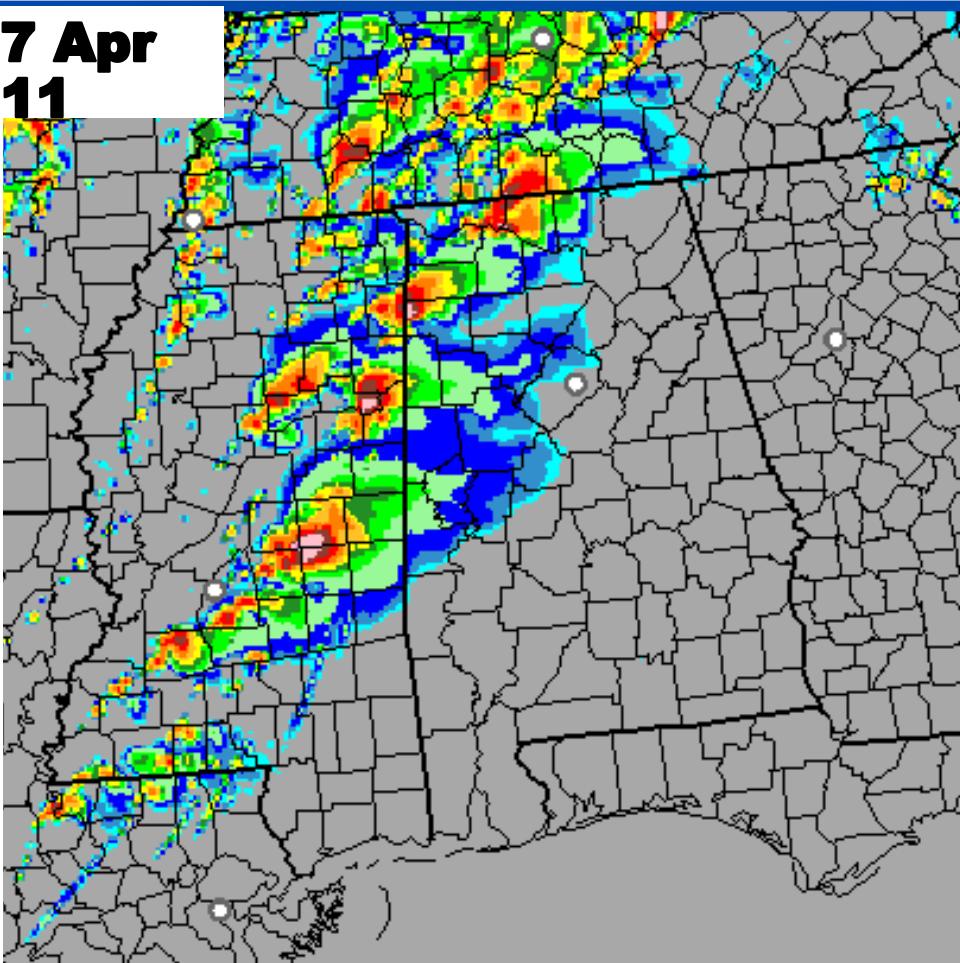


# HRRR Case Studies



**NSSL  
mosaic**

**20z 27 Apr  
2011**

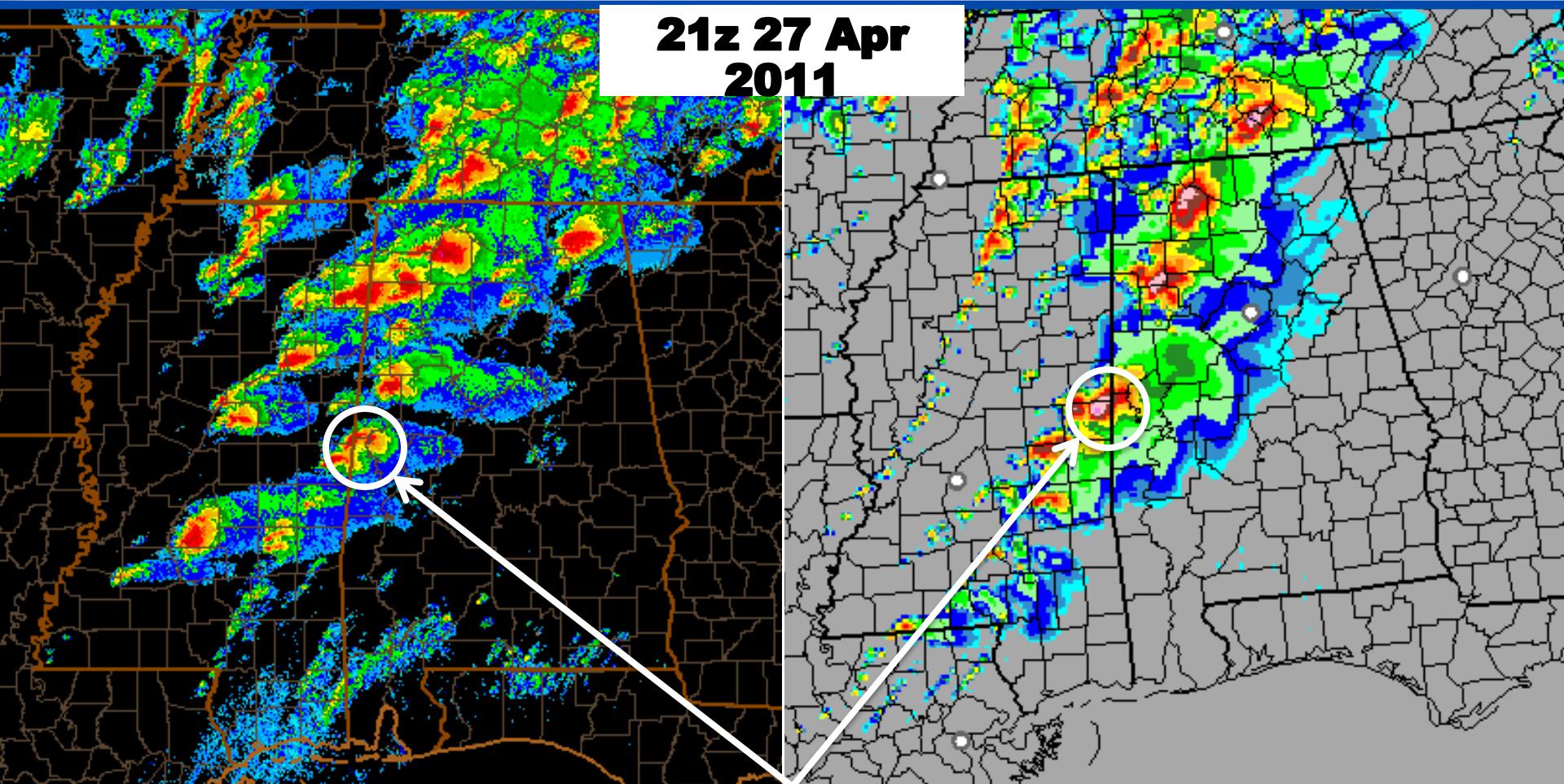


**HRRR**

**13z + 7 hr fcst**



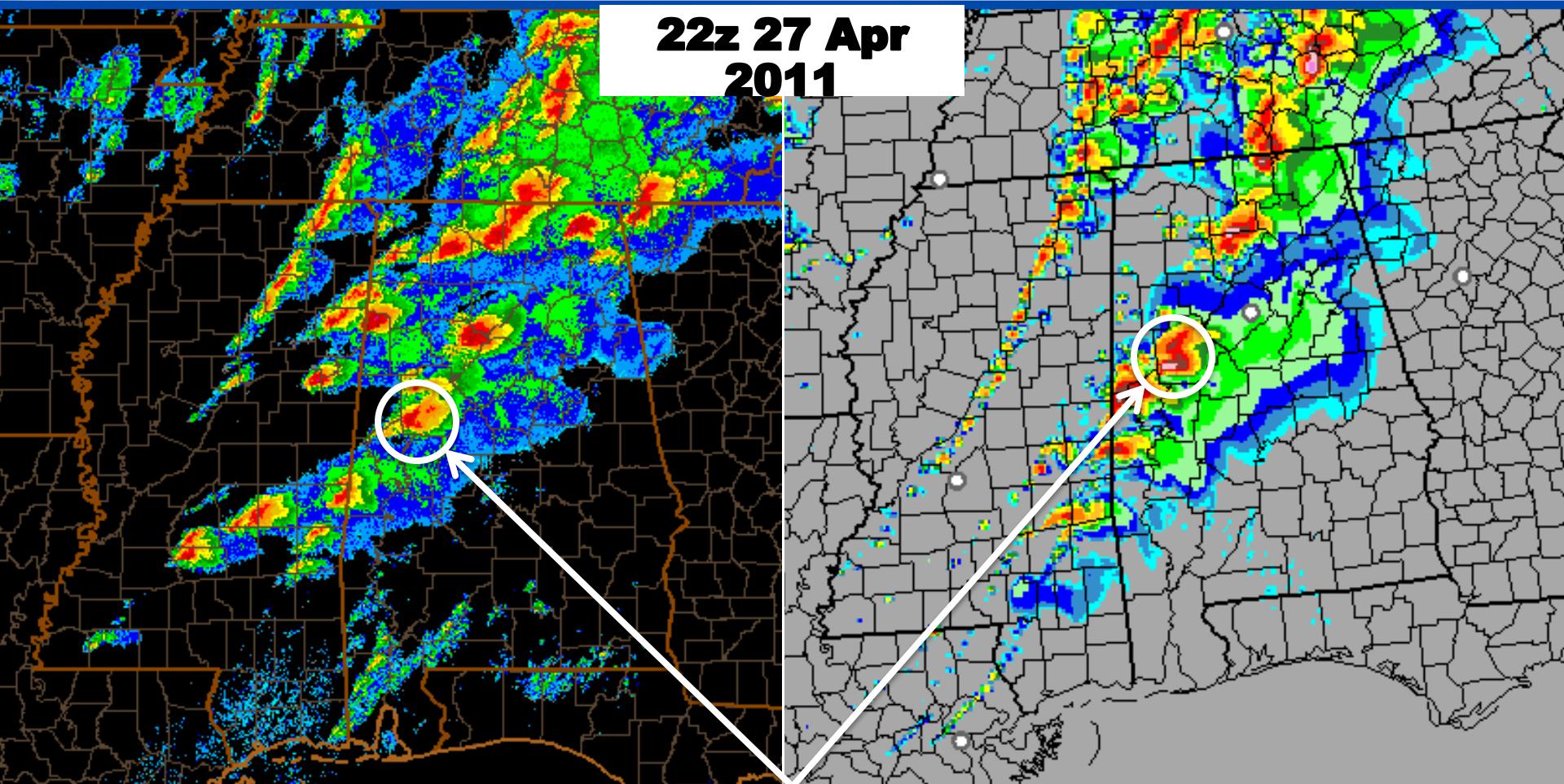
# HRRR Case Studies



**13z + 8 hr fcst**



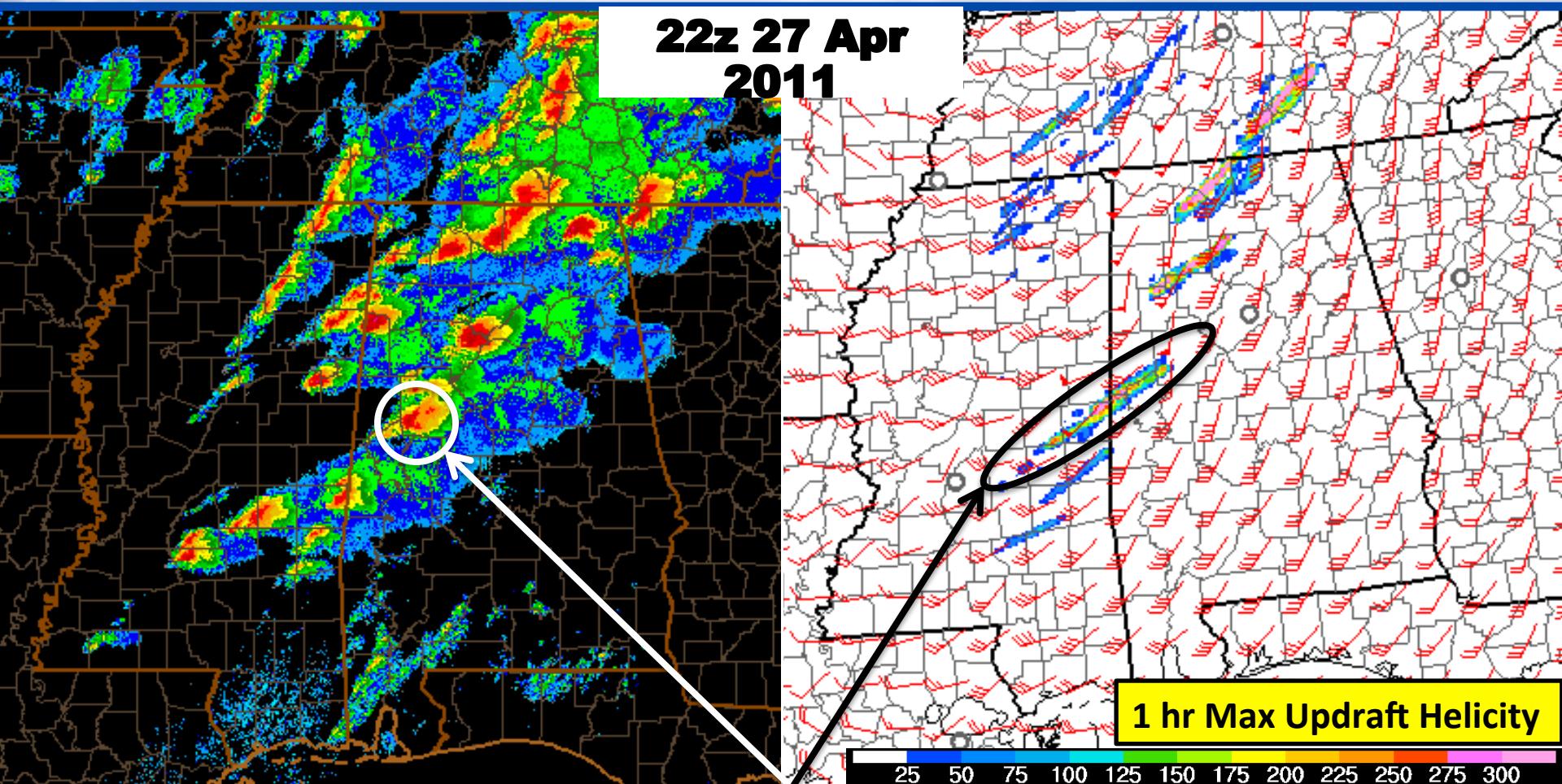
# HRRR Case Studies



**13z + 9 hr fcst**



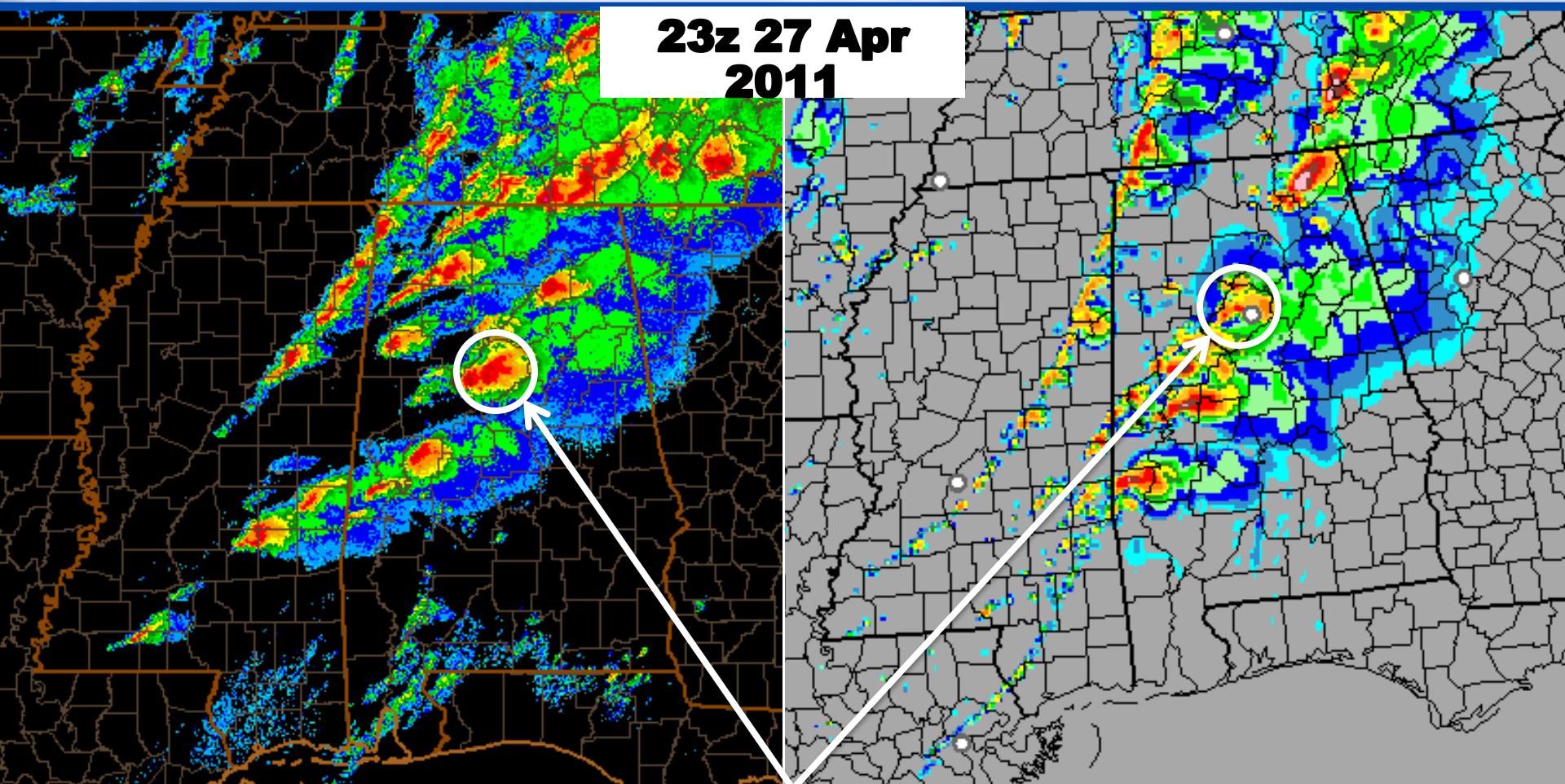
# HRRR Case Studies



**13z + 9 hr fcst**



# HRRR Case Studies



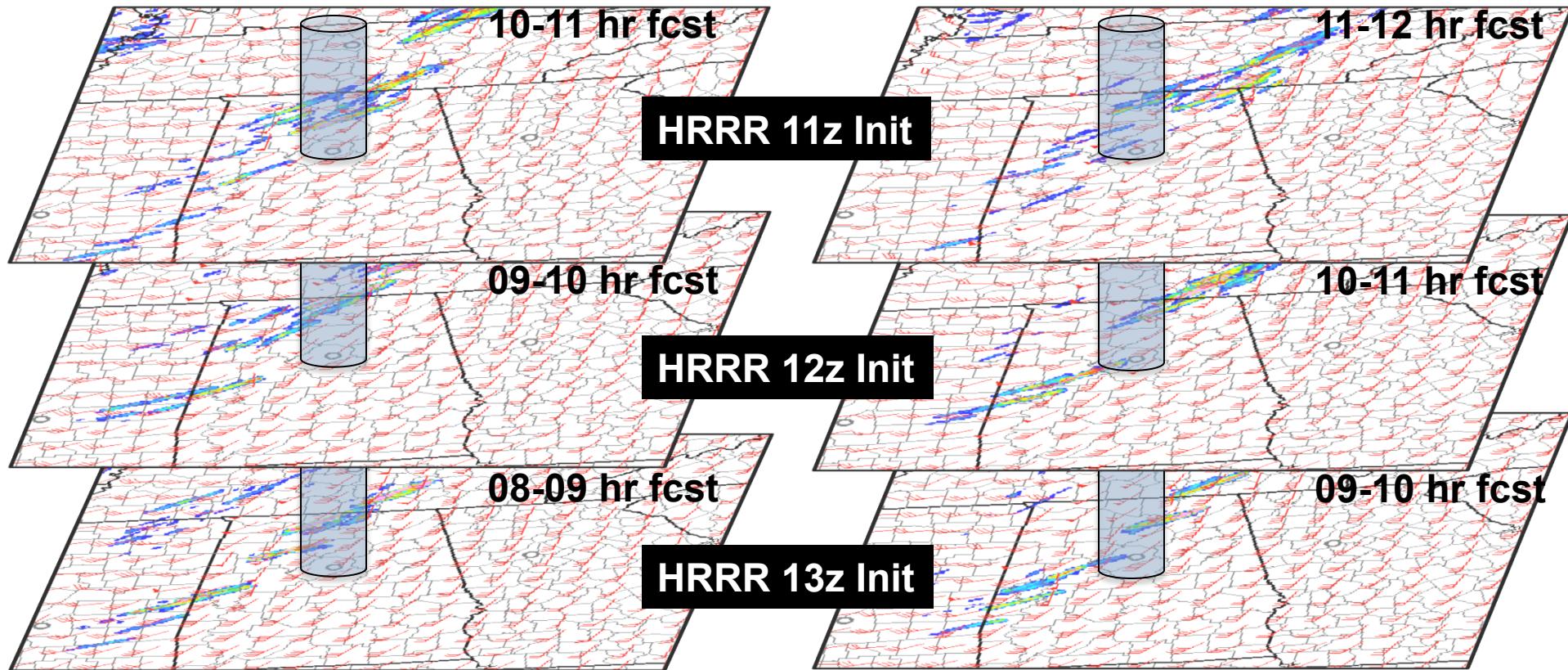
**13z + 10 hr fcst**



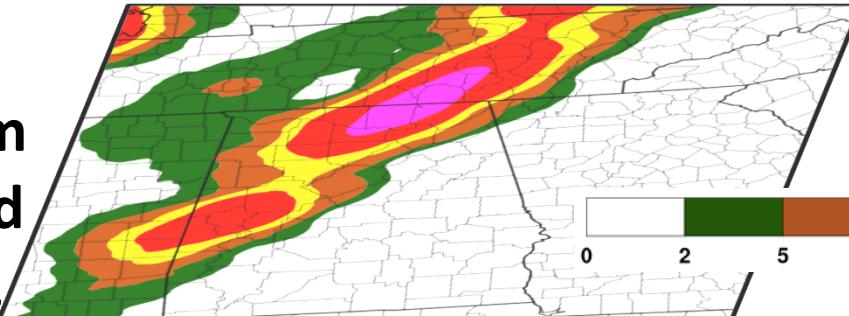
# Time-lagged Ensemble

Forecasts valid 21-22z 27 April 2011

Forecasts valid 22-23z 27 April 2011



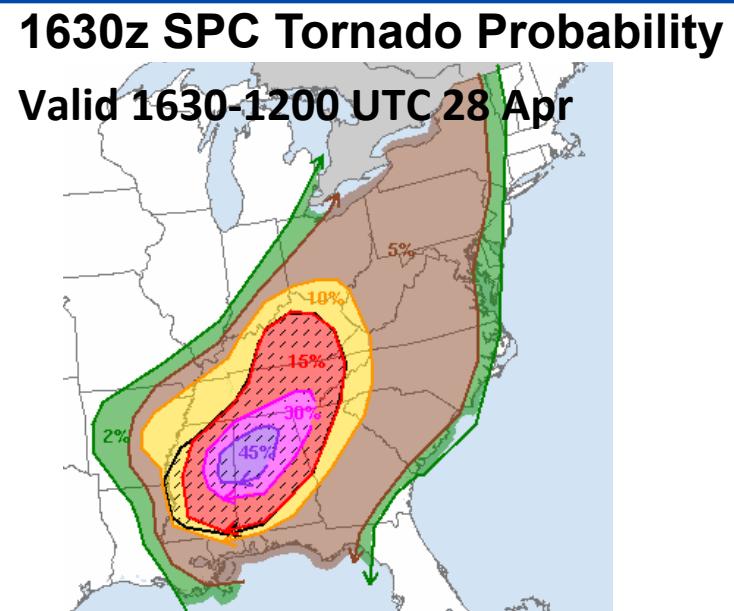
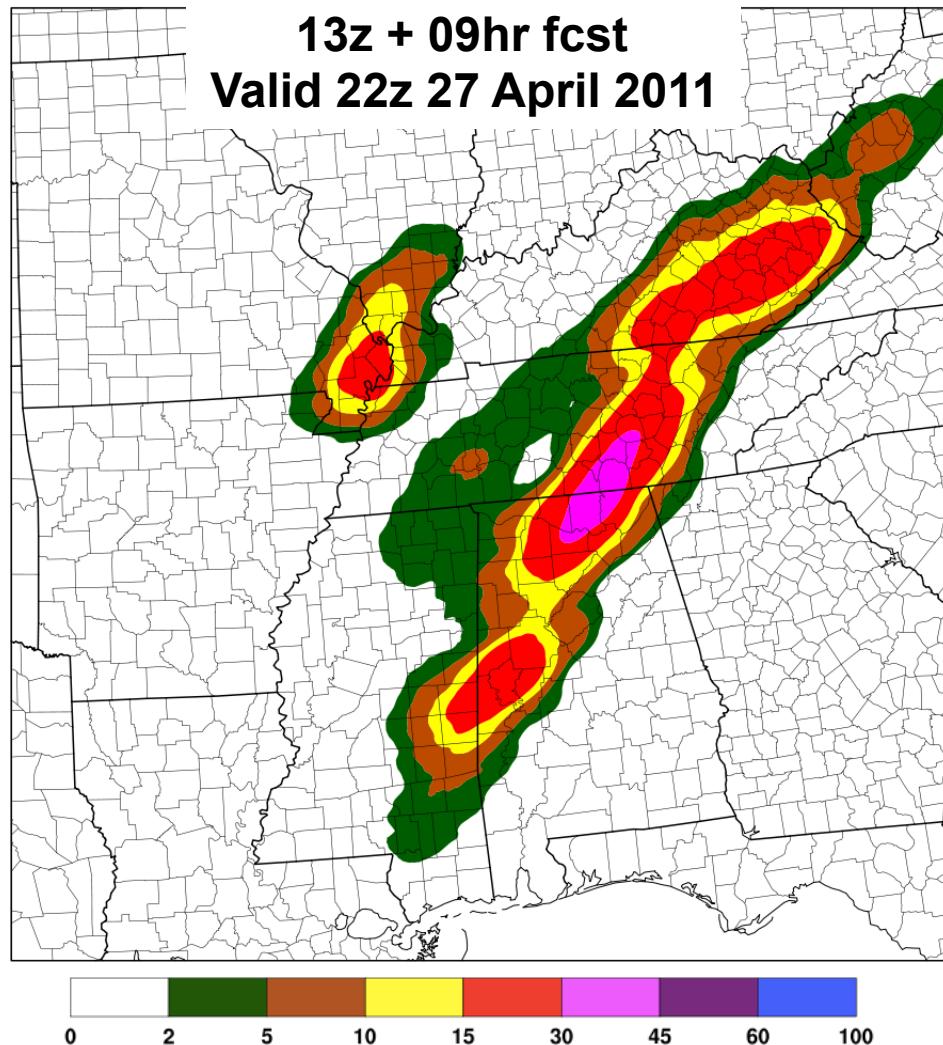
All six forecasts  
combined to form  
probabilities valid  
22z 27 April 2011



Spatial radius 45 km  
Time radius 1 hr  
UH threshold  $25 \text{ m}^2/\text{s}^2$



# Example: 27 April 2011

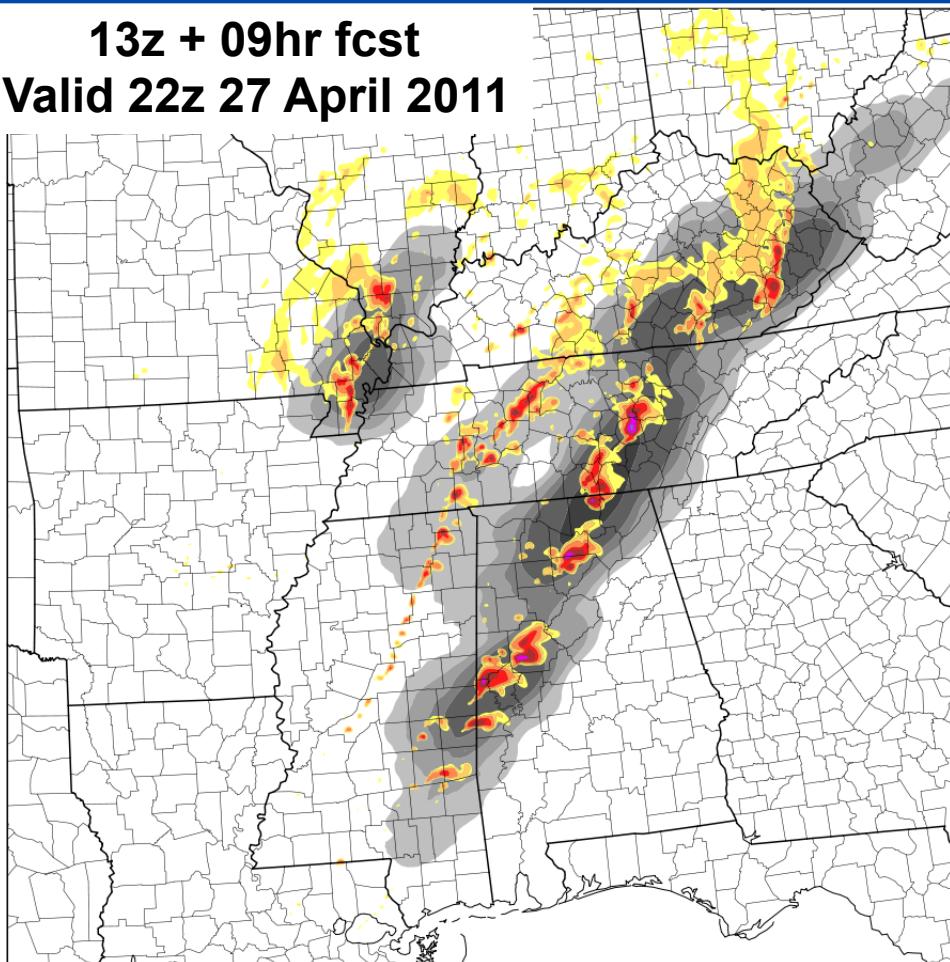




# Example: 27 April 2011

13z + 09hr fcst

Valid 22z 27 April 2011

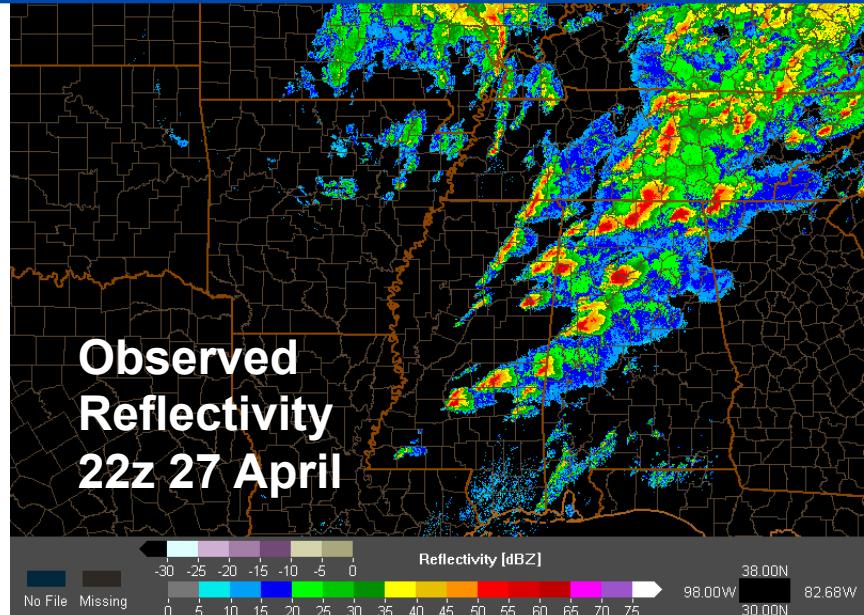


0 2 5 10 15 30 45 60 100

Tornadic Storm Probability (%)

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75

Reflectivity (dBZ)

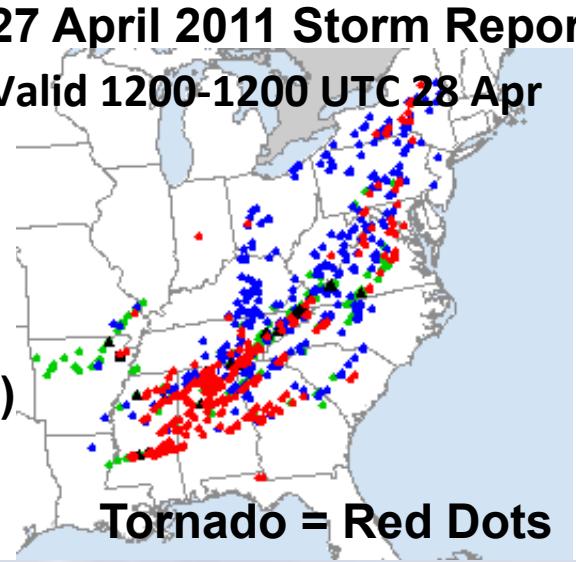


Observed  
Reflectivity  
22z 27 April

Reflectivity [dBZ]  
No File Missing  
-30 -25 -20 -15 -10 -5 0 38.00N 98.00W  
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 82.68W 30.00N

27 April 2011 Storm Reports

Valid 1200-1200 UTC 28 Apr



Tornado = Red Dots

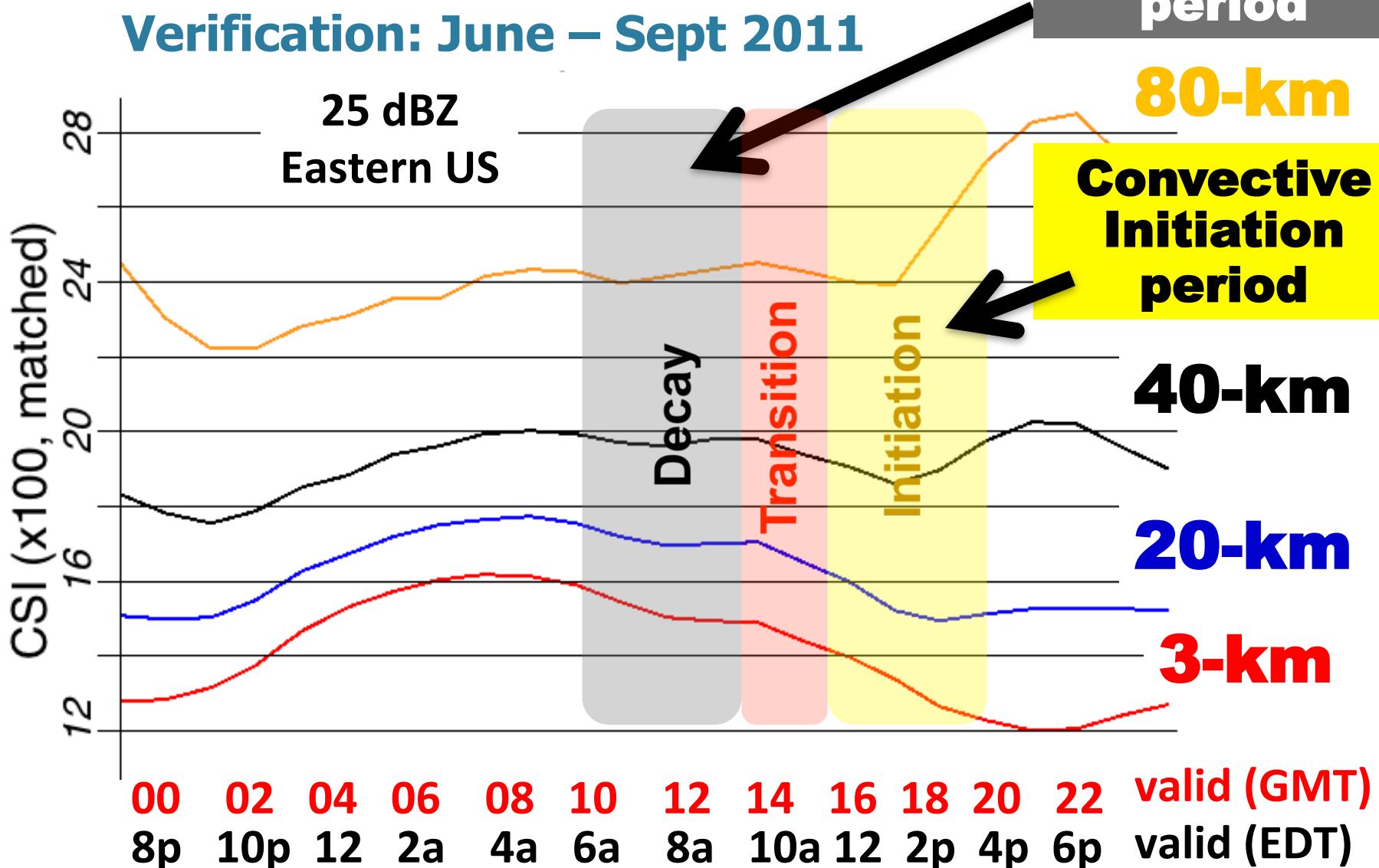


# HRRR Program Review Outline

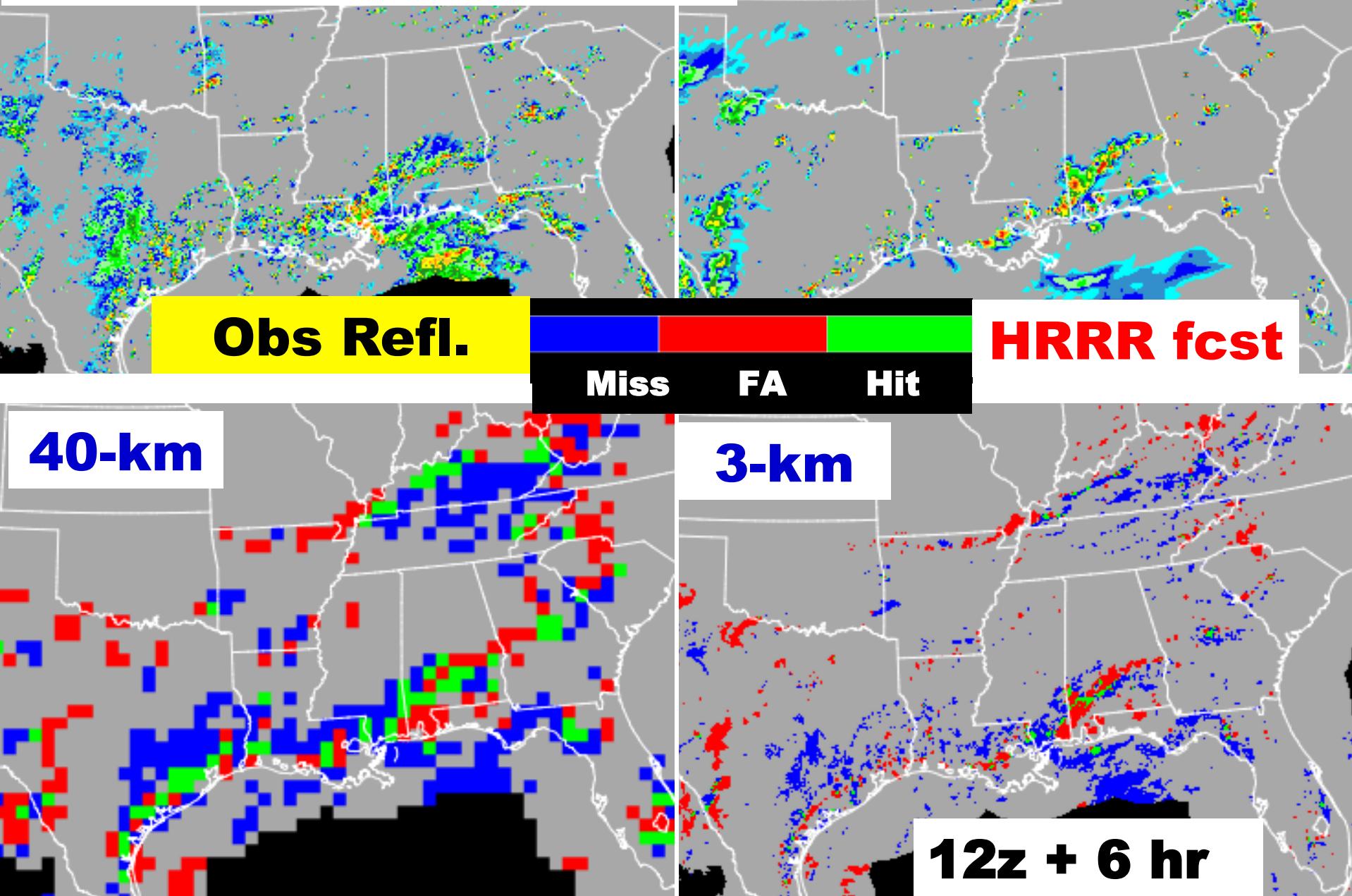
1:30	Opening Remarks	Stan Benjamin
1:30 – 1:40	Program Overview	Curtis Alexander
1:40 – 1:50	Initial Conditions: Rapid Refresh	Steve Weygandt
1:50 – 2:00	Model Development	David Dowell
2:00 – 2:10	Case Studies and Applications	Eric James
2:10 – 2:20	Forecast Verification	Patrick Hofmann
2:20	Summary and Future Plans	Curtis Alexander
2:20 – 2:30	Questions	

**Upscaled verification of all forecasts from 3-km HRRR**  
**Verification: June – Sept 2011**

**Convective Decay period**



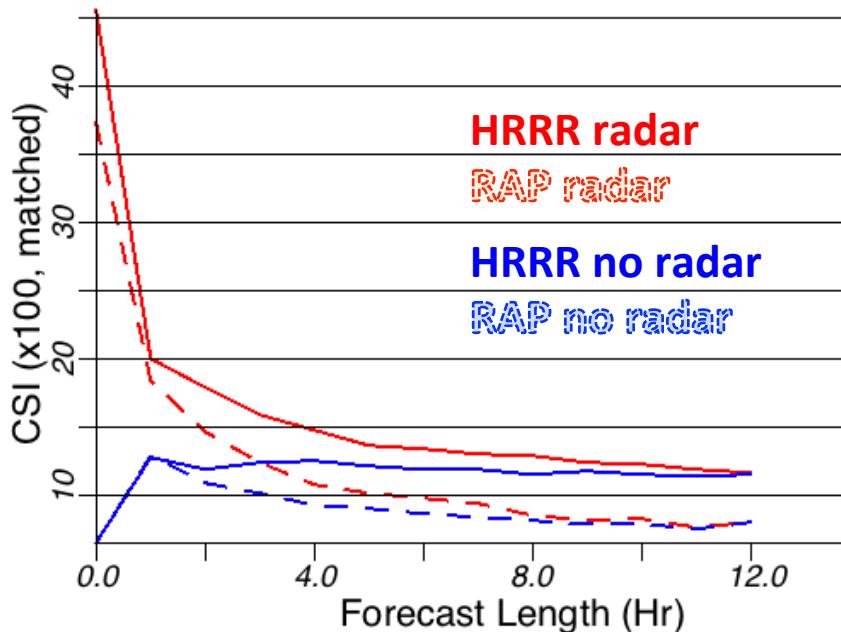
# Single case plots showing upscaled skill



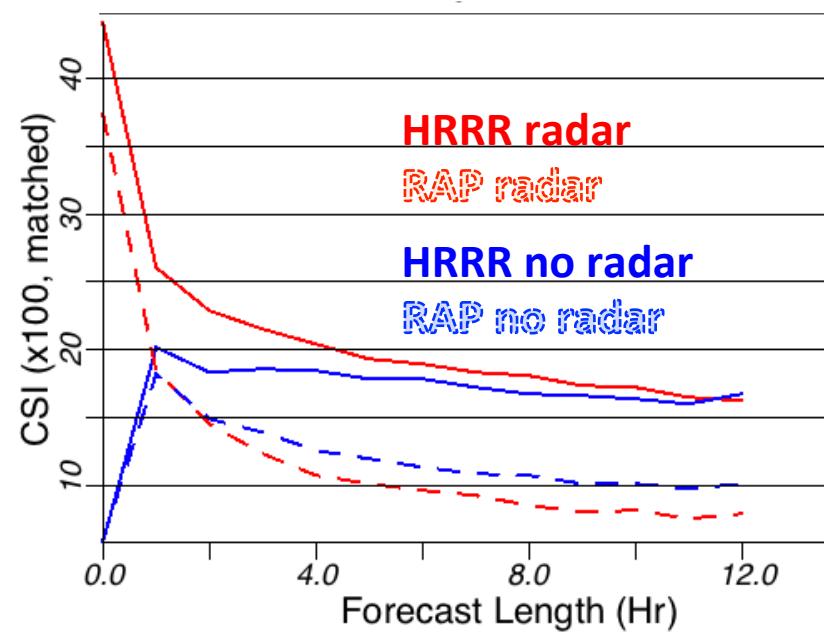
# RAP/HRRR Reflectivity Verification

Eastern US, Reflectivity > 25 dBZ  
11-21 August 2011

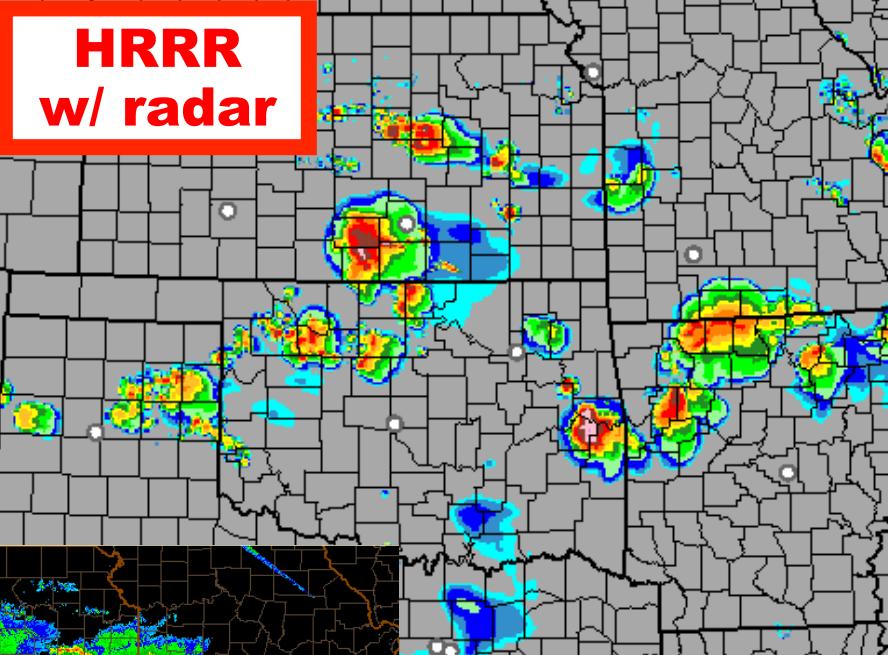
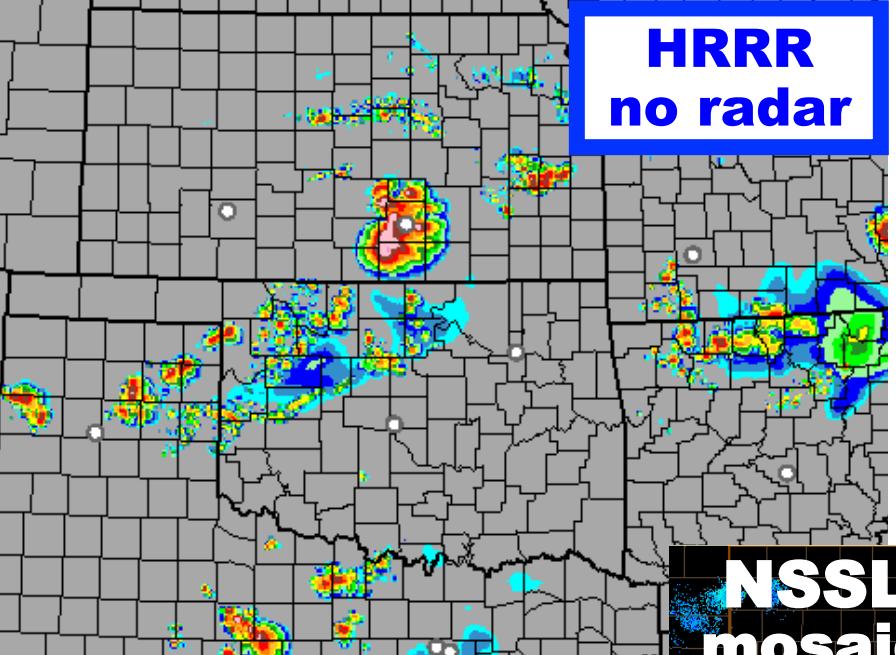
CSI 13 km



CSI 40 km



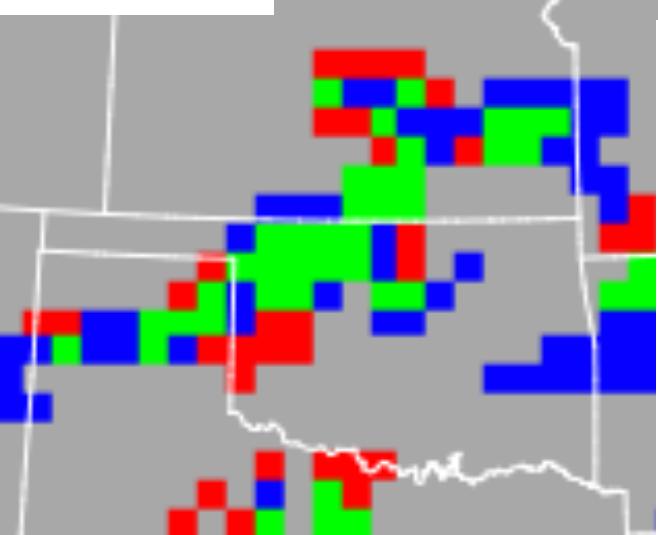
- 3km HRRR forecasts improve upon RAP 13km forecasts, especially at coarser scales → much better upscaled skill
- Radar DDFI adds skill at both 13km and 3km



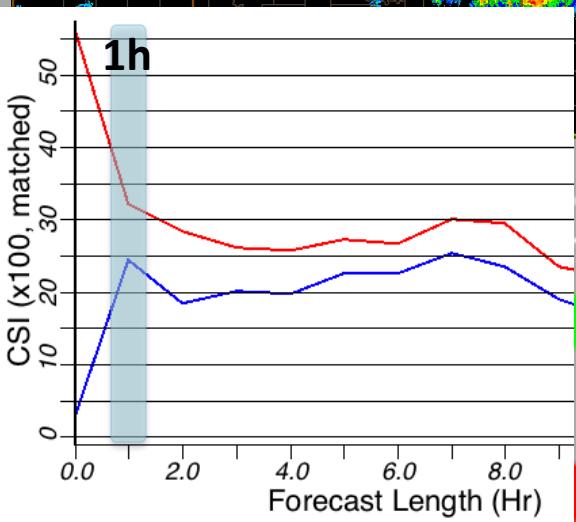
00z + 1 hr fcsts



CSI=.25

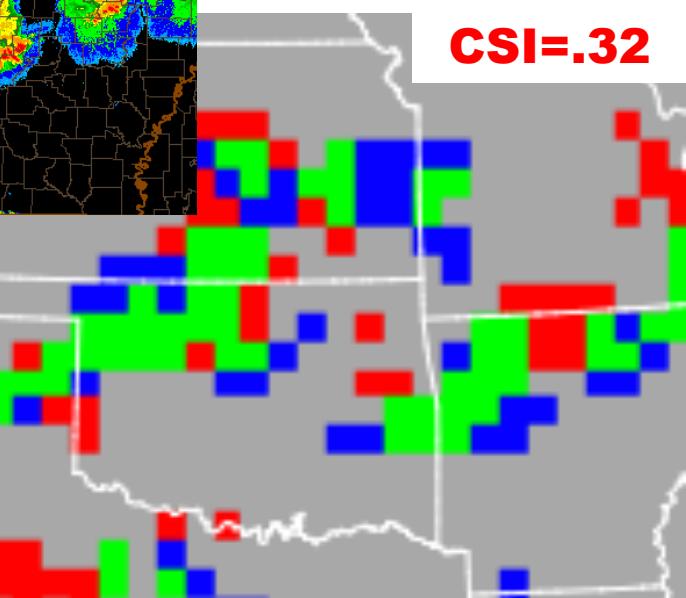


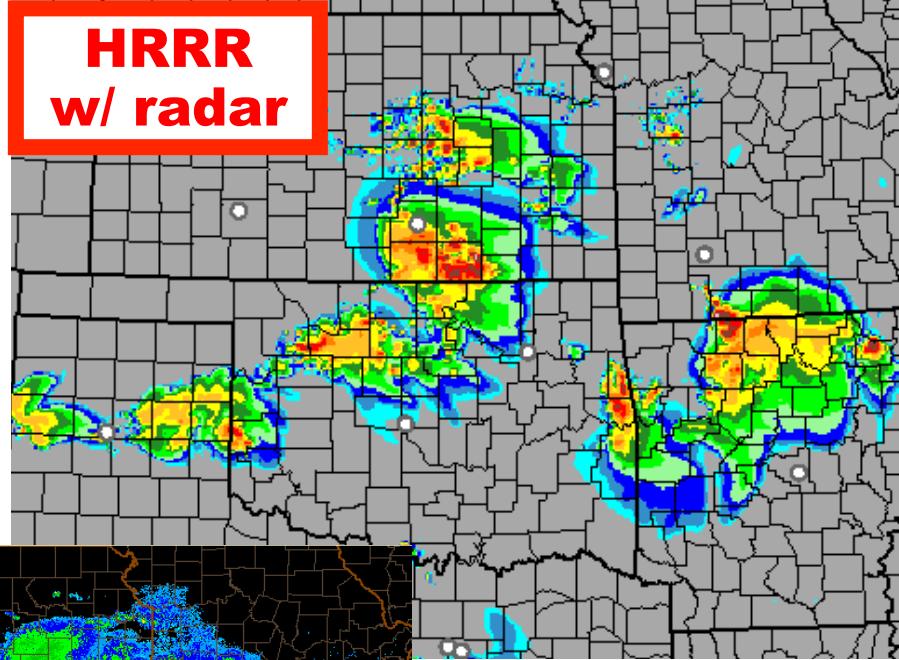
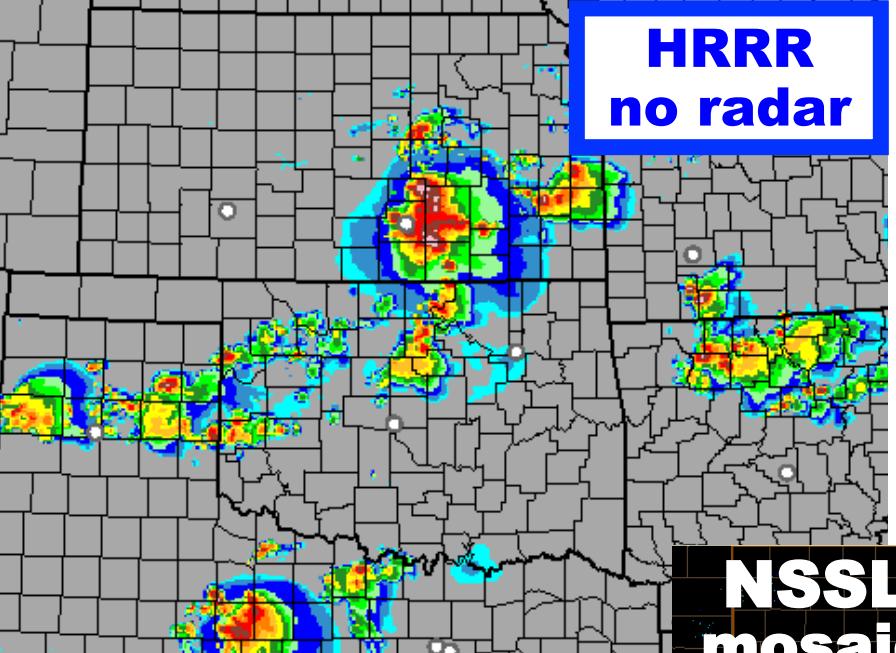
NSSL  
mosaic



01z 13 Aug  
2011

CSI=.32





00z + 2 hr fcsts

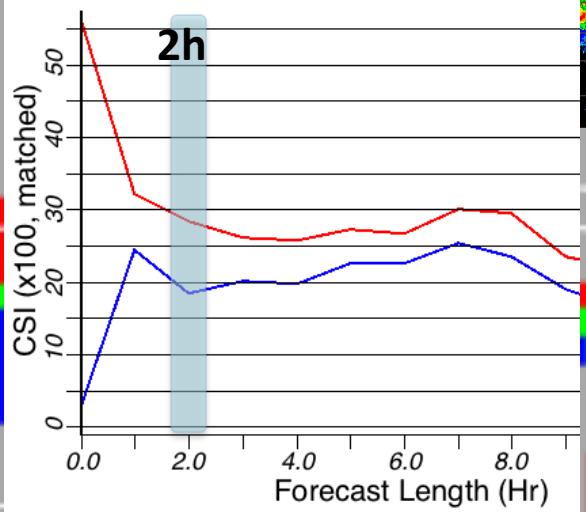
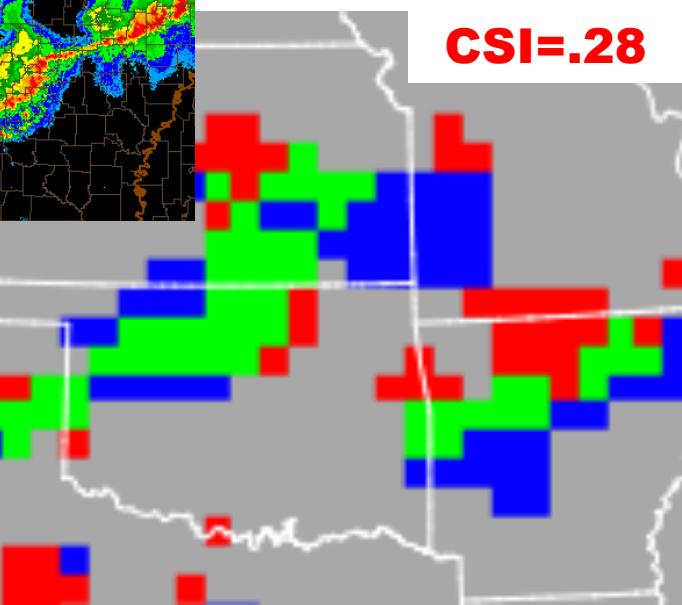
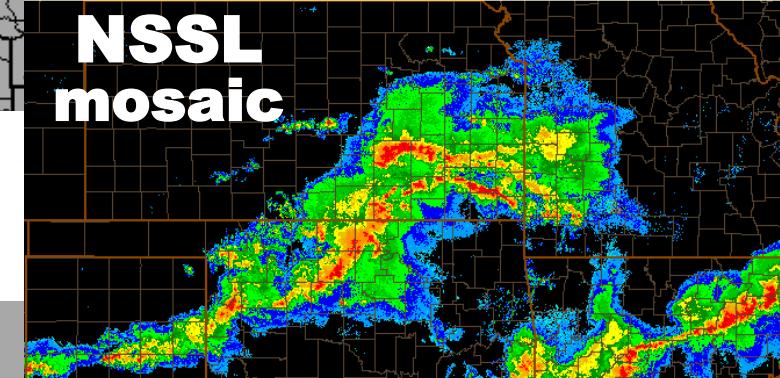
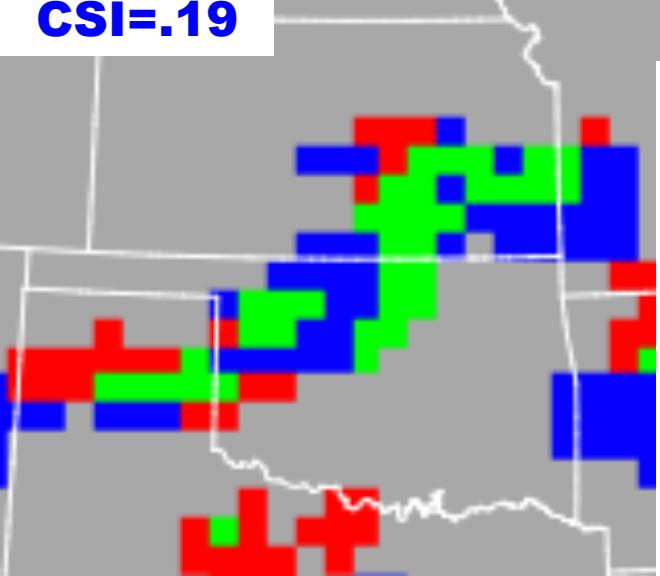
NSSL  
mosaic

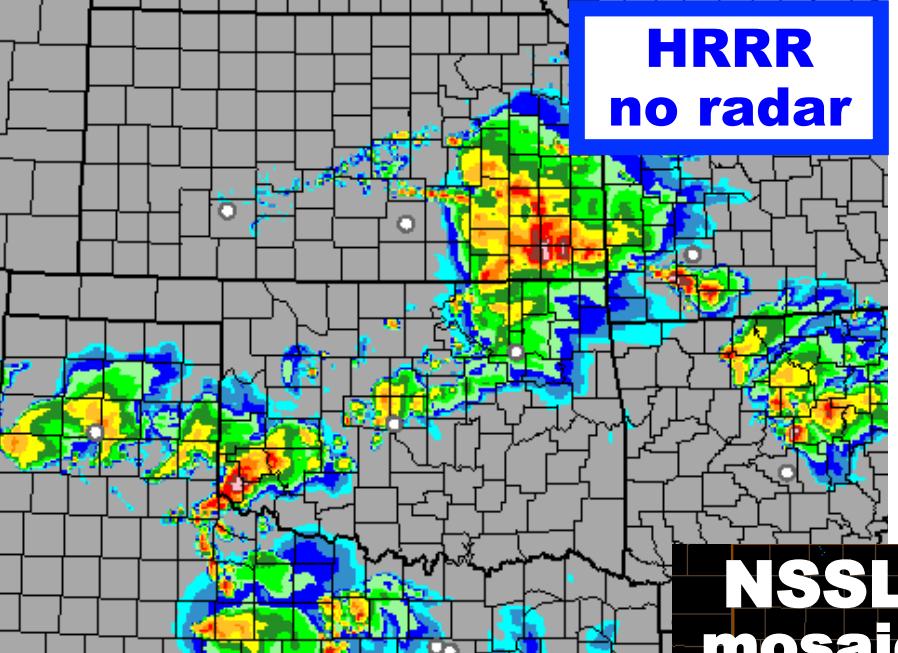
02z 13 Aug  
2011

Miss FA Hit

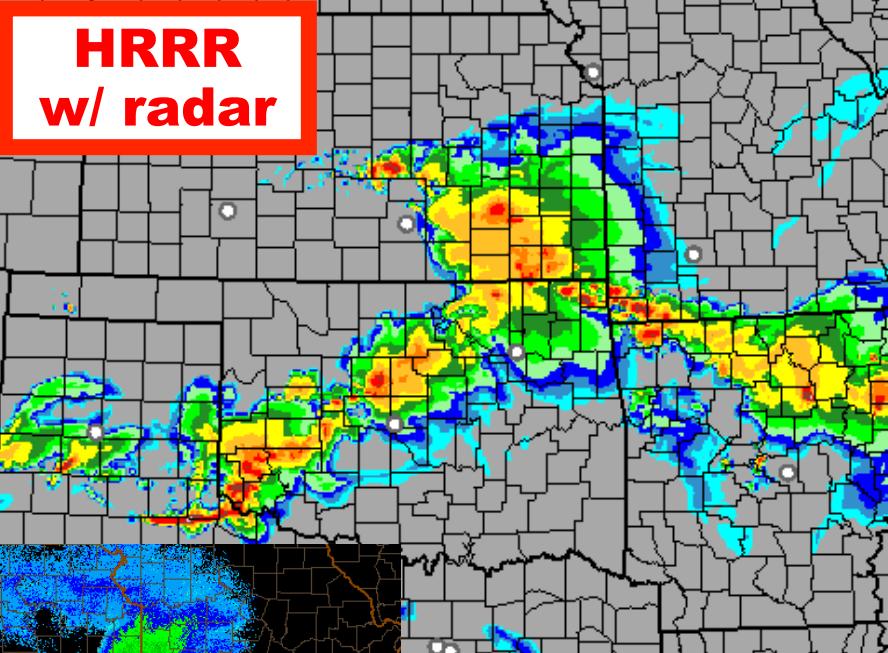
CSI=.19

CSI=.28





HRRR  
no radar



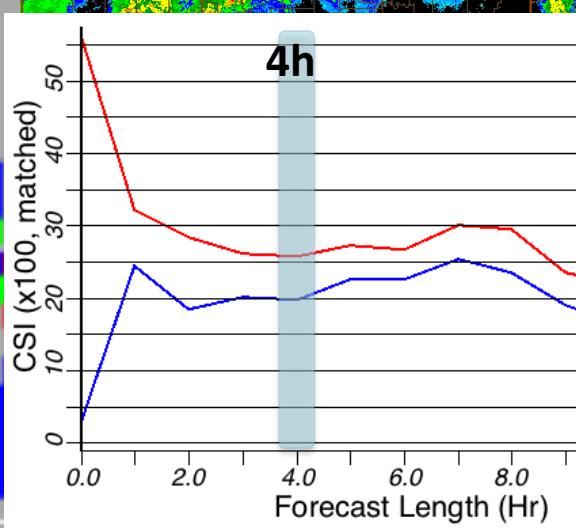
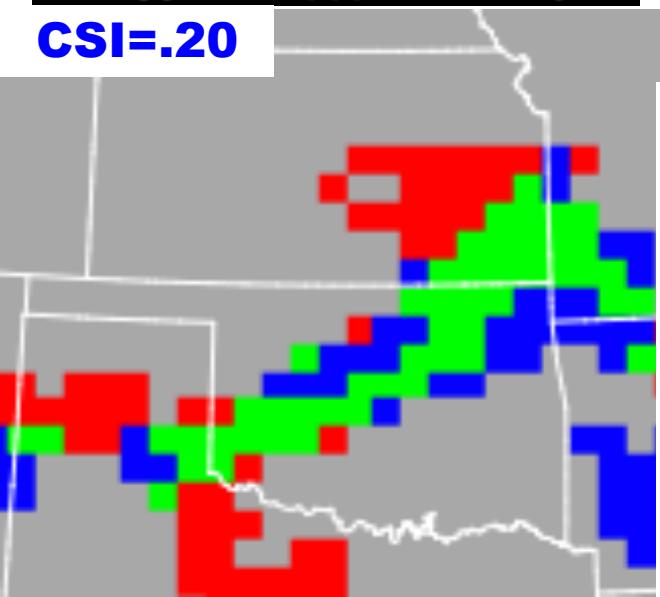
HRRR  
w/ radar

NSSL  
mosaic

00z + 4 hr fcsts

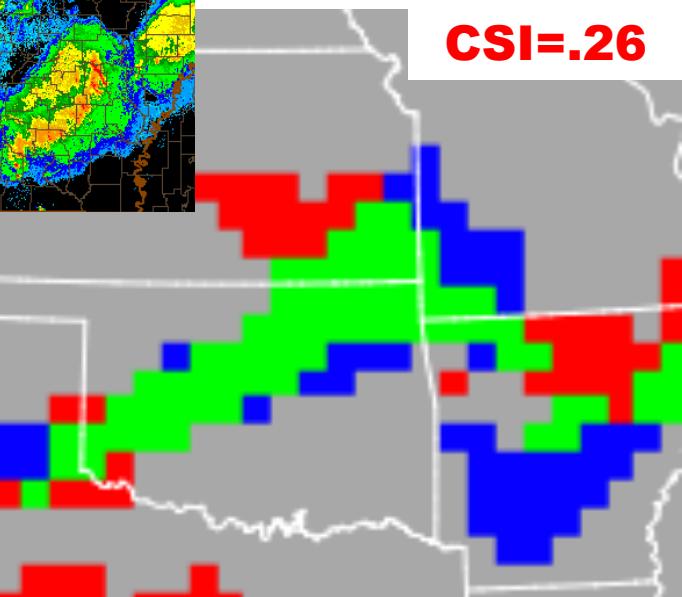
Miss FA Hit

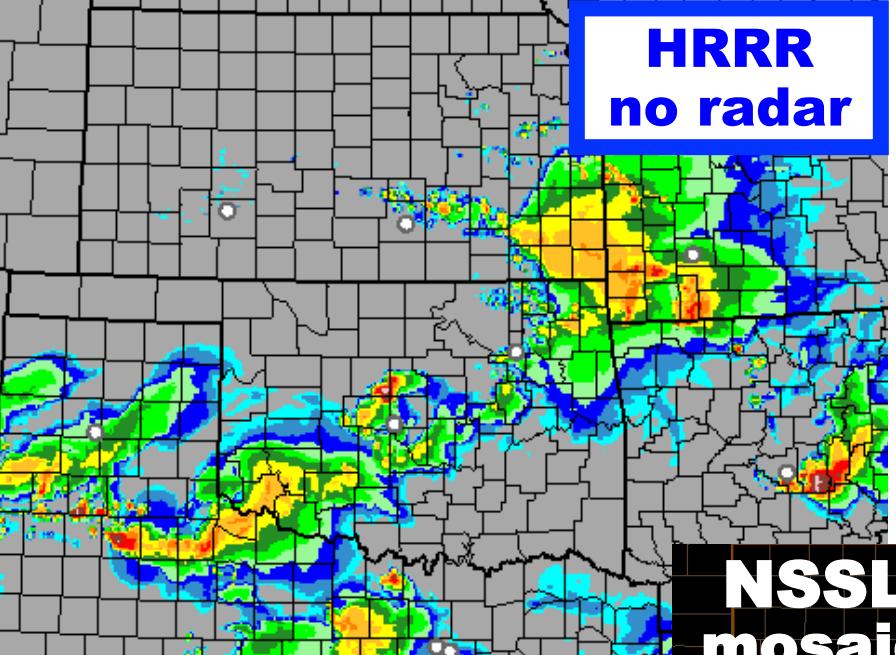
CSI=.20



04z 13 Aug  
2011

CSI=.26

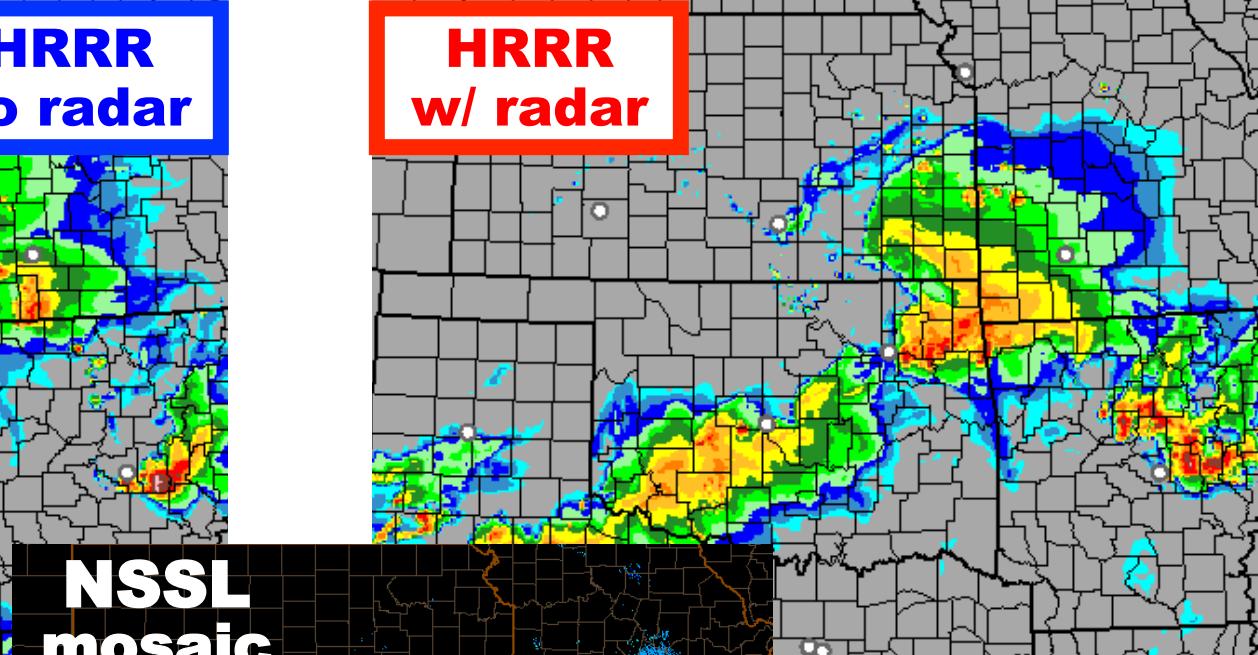
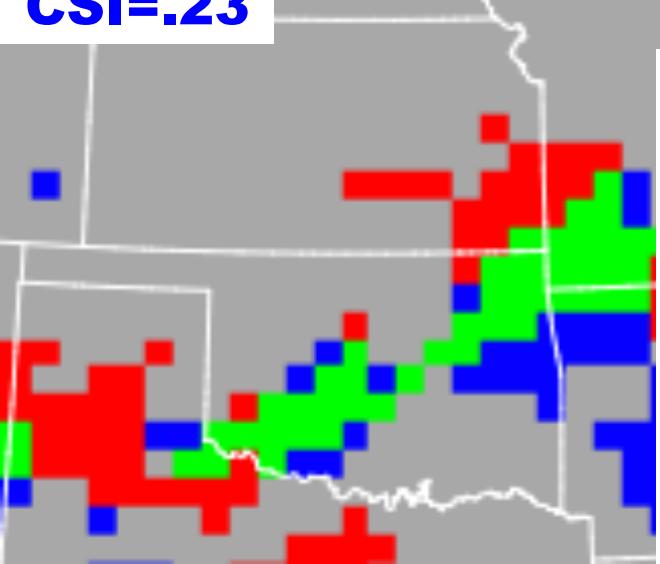




00z + 6 hr fcsts

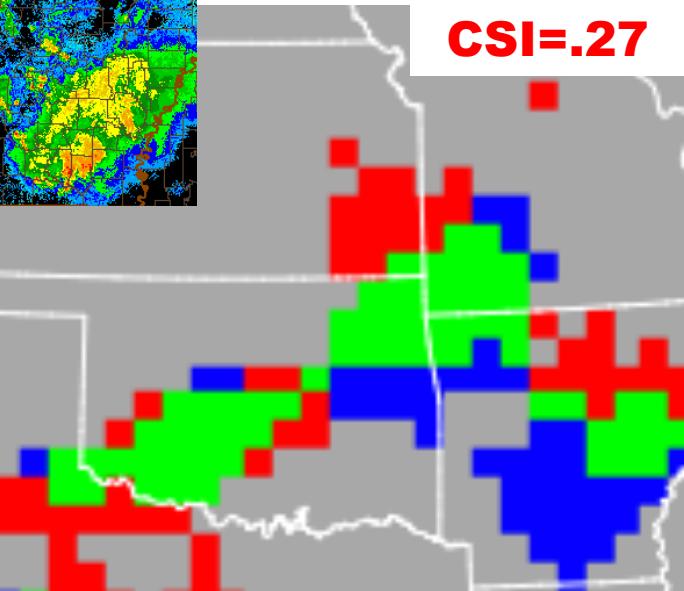
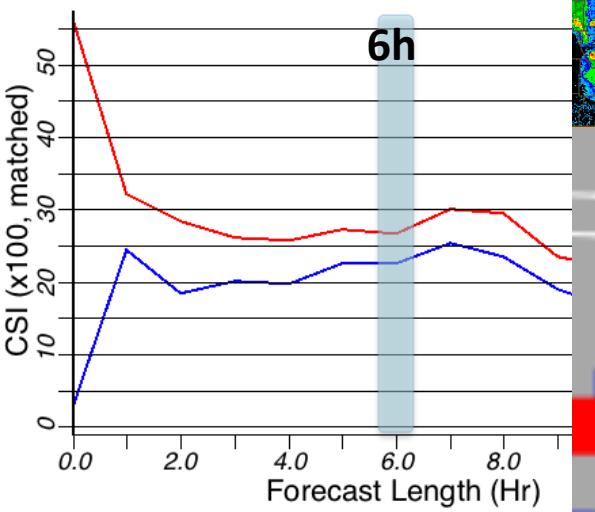
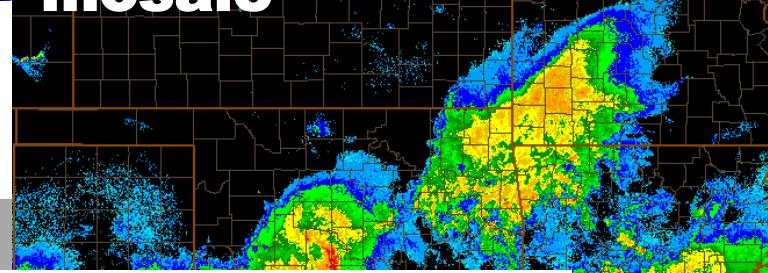


CSI=.23



06z 13 Aug  
2011

CSI=.27

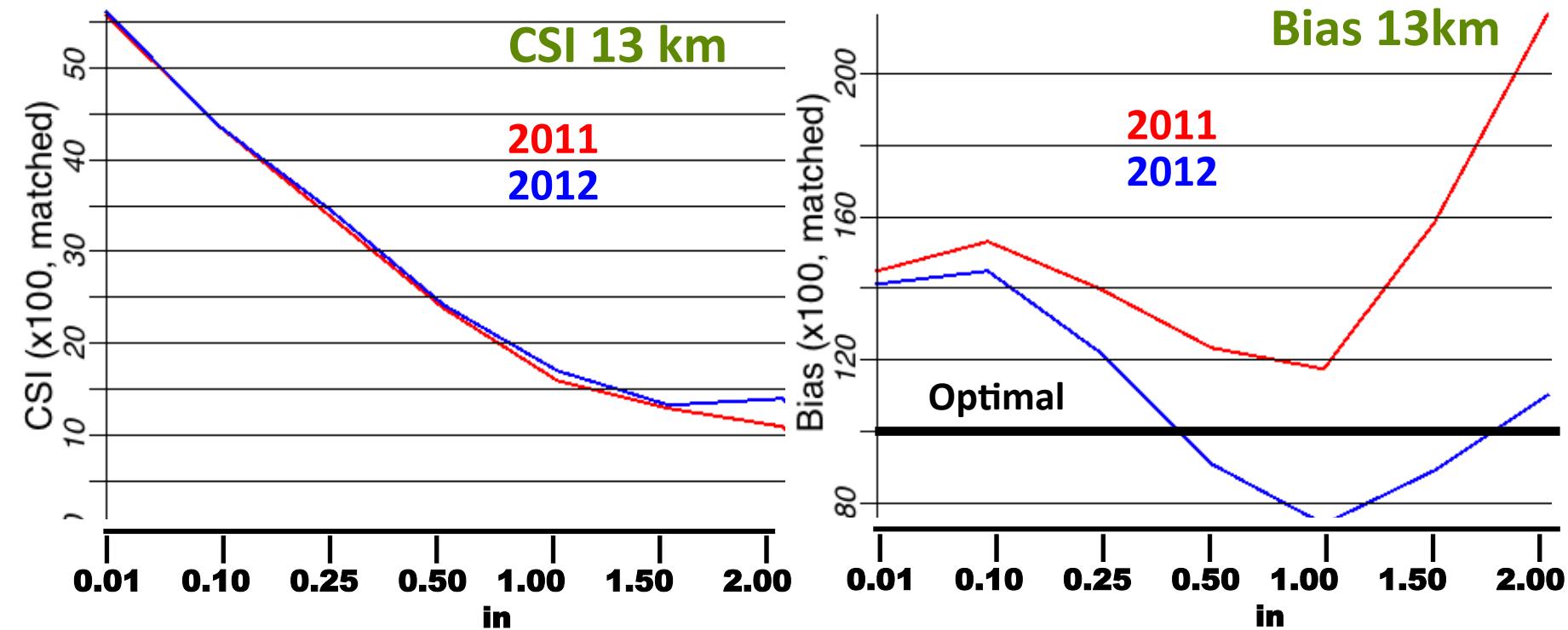


# 2011 vs. 2012 RAP

## Precipitation Verification

Eastern US, 2x12hr Forecasts vs. 24h CPC

11-21 August 2011



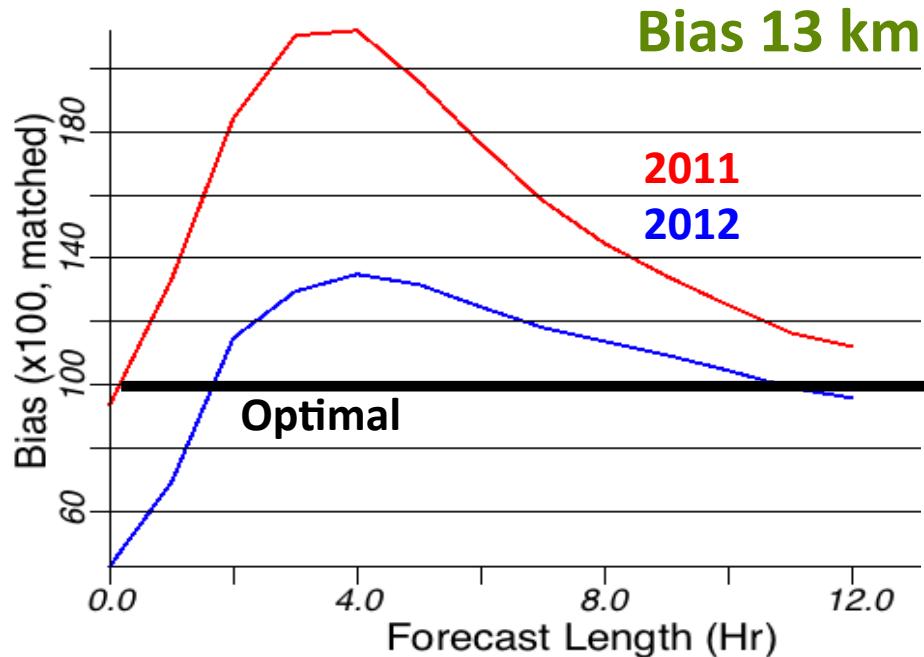
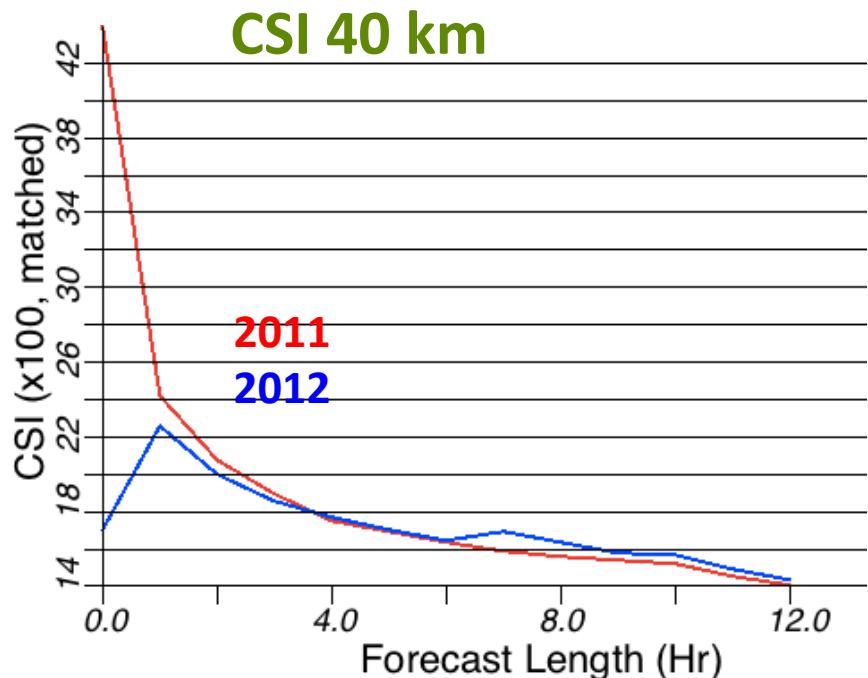
Forecast skill maintained, and even improved at the highest thresholds  
2012 configuration has a MUCH reduced bias!

# 2011 vs. 2012 HRRR

## Reflectivity Verification

Eastern US, Reflectivity > 25 dBZ

11-21 August 2011



Forecast skill similar, but 2012 configuration  
has a MUCH reduced bias!

# Verification of HRRR vs RAP-ESRL

Cold Season (29 Jan 2012 – 10 Mar 2012)

HRRR vs RAP

Lead Time	Clouds		Precip (13 km)		Reflectivity (40 km)		Upper-Air			Surface		
	Ceiling < 500 ft	Vis < 0.5 mile	> 0.1 inch	> 1.0 inch	25 dBZ	35 dBZ	Temp	RH	Wind	Temp	Dewpt	Wind
3-hr	Equal	HRRR	N/A	N/A	Equal	HRRR	HRRR	HRRR	Equal	HRRR	Equal	HRRR
6-hr	HRRR	Equal			HRRR	HRRR	HRRR	HRRR	Equal	HRRR	HRRR	HRRR
12-hr	HRRR	HRRR			HRRR	HRRR	HRRR	RAP	RAP	HRRR	HRRR	HRRR

Warm Season (15 April 2011 – 25 October 2011)

HRRR vs RAP

Lead Time	Clouds		Precip (13 km)		Reflectivity (40 km)		Upper-Air			Surface		
	Ceiling < 500 ft	Vis < 0.5 mile	> 0.1 inch	> 1.0 inch	25 dBZ	35 dBZ	Temp	RH	Wind	Temp	Dewpt	Wind
1-hr	HRRR	RAP	HRRR	Equal	HRRR	HRRR	HRRR	HRRR	HRRR	RAP	RAP	HRRR
3-hr	HRRR	HRRR			HRRR	HRRR	HRRR	HRRR	RAP	Equal	RAP	Equal
6-hr	HRRR	HRRR			HRRR	HRRR	HRRR	HRRR	RAP	HRRR	Equal	Equal

# HRRR vs. RAP-ESRL

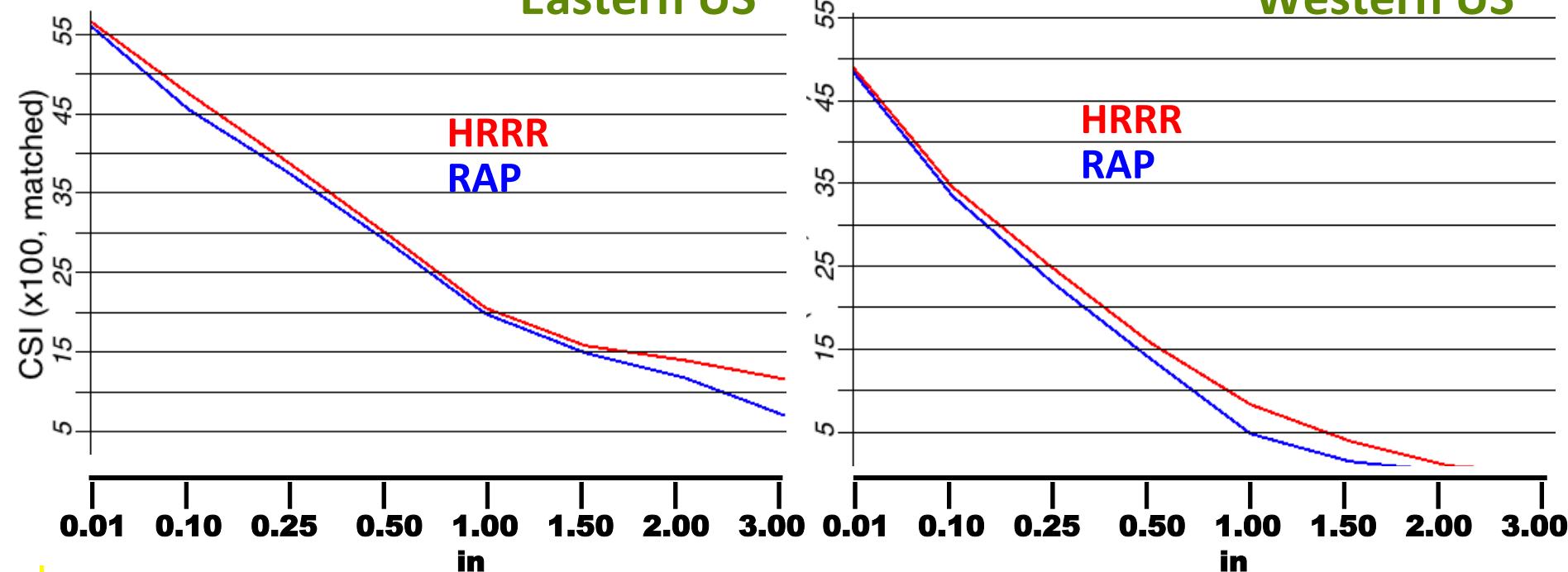
## Precipitation Verification

13km scale, 2x12hr Forecasts vs. 24h CPC

June - Sept 2011

Eastern US

Western US

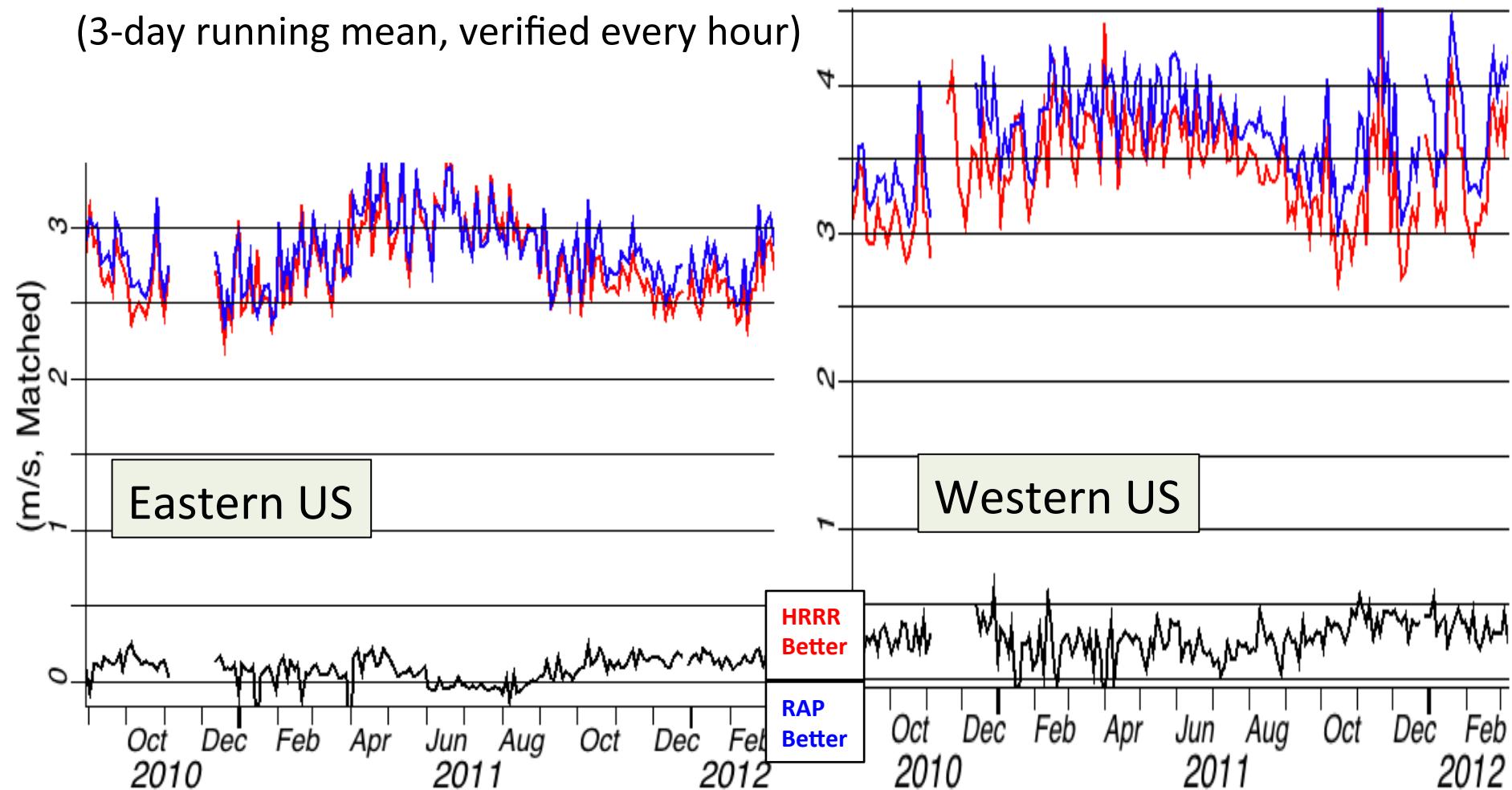


Forecast skill better in HRRR, especially at higher thresholds and in the Western US

# HRRR vs. RAP-ESRL – 12h forecasts

## 10m wind rms difference from METARs

(3-day running mean, verified every hour)



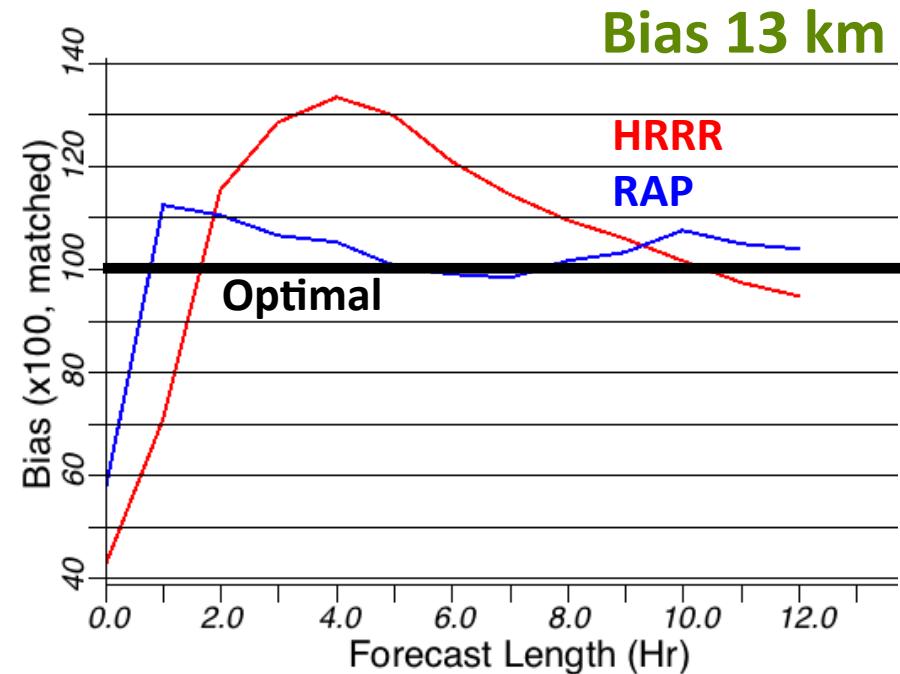
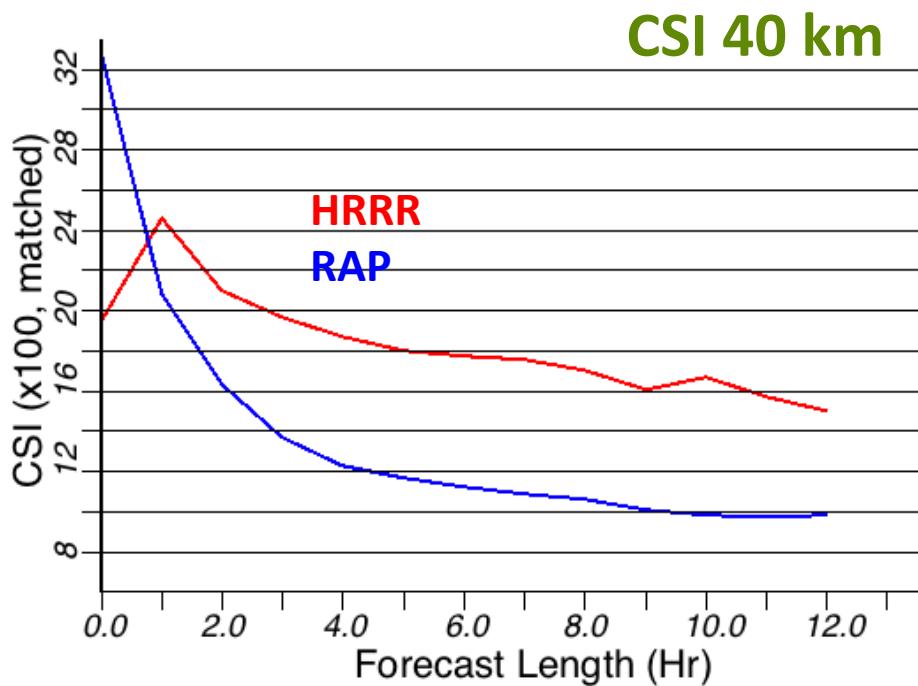
**HRRR more accurate than RAP, more so in western US, especially since Oct 2011**

# 2012 HRRR vs. 2012 RAP-ESRL

## Reflectivity Verification

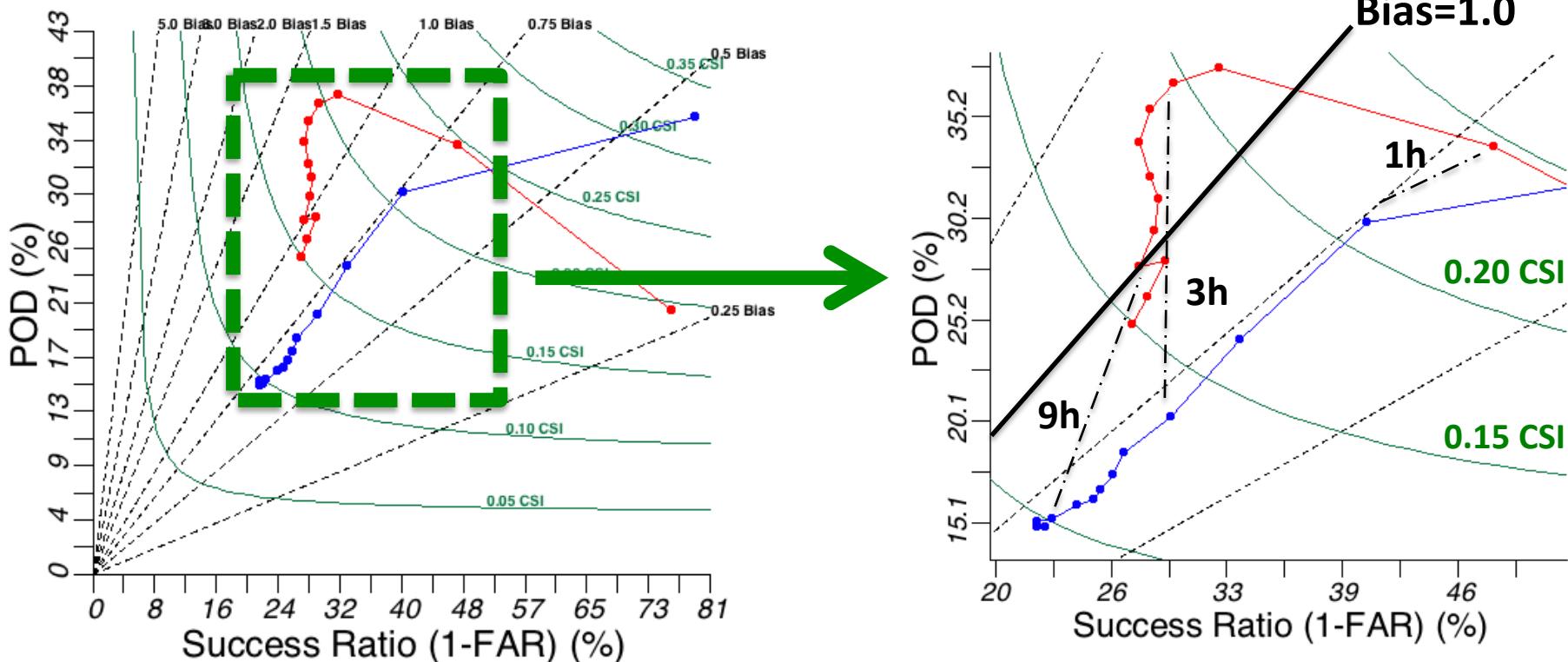
Eastern US, Reflectivity > 25 dBZ

Aug 2011



3km HRRR forecasts show much greater skill than 13km RAP forecasts, while maintaining very similar biases

# 2012 HRRR vs. 2012 RAP-ESRL Performance Diagrams



**HRRR has more optimal Bias and higher CSI**



# HRRR Program Review Outline

1:30	Opening Remarks	Stan Benjamin
1:30 – 1:40	Program Overview	Curtis Alexander
1:40 – 1:50	Initial Conditions: Rapid Refresh	Steve Weygandt
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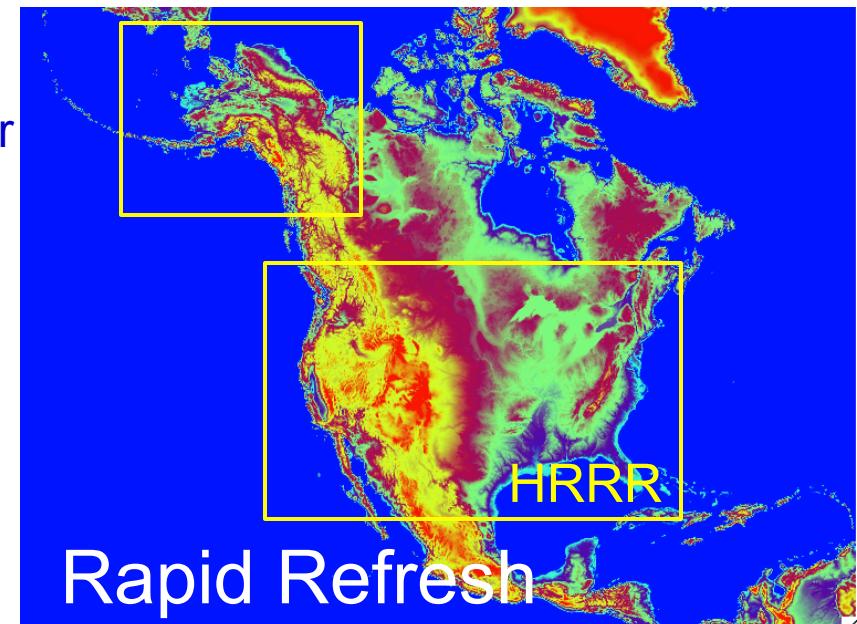


# Future Plans for Hourly Updated Models

- Mar 2012 – Rapid Refresh operational at NCEP
- Early 2013 – Rapid Refresh v2 –
  - cloud/surface/soil assimilation → much lower moist bias (better convective fcsts), GOES, sodar/tower/nacelle winds, updated GSI
  - model – MODIS land use, cloud/PBL/numerical improvements, updated WRF
- 2013 – application of hybrid/EnKF assimilation to RAP in real-time testing
- 2012-14 – HRRR @ESRL improves, add Fairmont/zeus HRRR to reach 99%
- 2015 – High-Resolution Rapid Refresh operational at NCEP for CONUS

## N.American Rapid Refresh Ensemble

- NEMS-based NMM, ARW cores
- Hourly updating with GSI-hybrid EnKF
- Initially 6 members, 3 each core, physics diversity (RAP, NAM, NCAR suites)
- Forecasts to 24-h
- NMM to 84-h 4x per day



- 2015 – Ensemble Rapid Refresh – **NARRE** w/ hybrid assim
- 2016 – Add operational Alaska HRRR
- 2017 – CONUS Ensemble HRRR – **HRRRE**

## Other improvements in init testing

- RAP with inline chem, chem DA
- 15-min radar data assimilation
- Storm-scale radar data assimilation



# HRRR Program Review Outline

1:30	<b>Opening Remarks</b>	Stan Benjamin
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2:10 – 2:20	<b>Forecast Verification</b>	Patrick Hofmann
2:20	<b>Summary and Future Plans</b>	Curtis Alexander
2:20 – 2:30	<b>Questions</b>	



# List of Acronyms

AMB	Assimilation and Modeling Branch
AMSU	Advanced Microwave Sounding Unit
ARL	Air Resources Laboratory
ARW	Advanced Research WRF (Model)
AWIPS	Advanced Weather Interactive Processing System
CIWS	Corridor Integrated Weather System
CONUS	Contiguous United States
CoSPA	Consolidated Storm Prediction for Aviation (FAA experimental thunderstorm forecast program)
CPC	Climate Prediction Center
CIRA	Cooperative Institute for Research in the Atmosphere
CSI	Critical Success Index
CSU	Colorado State University
DA	Data Assimilation
DDFI	Diabatic Digital Filter Initialization
DFI	Digital Filter Initialization
DOE	Department of Energy
DTC	Developmental Testbed Center
EnKF	Ensemble Kalman Filter
ESRL	Earth System Research Laboratory
FAA	Federal Aviation Administration
FAR	False Alarm Ratio
FTP	File Transfer Protocol
G3	Grell Three Dimensional (Convective Parameterization Scheme)
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GSD	Global Systems Division
GSI	Gridpoint Statistical Interpolation
HPCC	High Performance Computer Consortium
HPCS	High Performance Computer System
HRRR	High-Resolution Rapid Refresh (Model)



# List of Acronyms (continued)

HRRRE	High-Resolution Rapid Refresh Ensemble
LDM	Local Data Manager
METAR	Aviation routine weather report
MIT/LL	Massachusetts Institute of Technology/Lincoln Laboratory
MODIS	MODerate resolution Imaging Spectroradiometer
MYJ	Mellor-Yamada-Janjic (Boundary Layer Scheme)
NCAR	National Center for Atmospheric Research
NARRE	North American Rapid Refresh Ensemble
NCEP	National Centers for Environmental Prediction
NEMS	NOAA Environmental Modeling System
NAM	North American Mesoscale (Model)
NMM	Non-hydrostatic Mesoscale Model
NMMB	Non-hydrostatic Mesoscale Model B-Grid
NOAA	National Oceanic and Atmospheric Administration
NSSL	National Severe Storms Laboratory
NWS	National Weather Service
PBL	Planetary Boundary Layer
POD	Probability of Detection
RAP	Rapid Refresh (Model)
RASS	Radio Acoustic Sounding System
RMS	Root Mean Square
RRTM	Rapid Radiative Transfer Model
RTMA	Real Time Mesoscale Analysis (Hourly updated surface analysis from NCEP)
RUC	Rapid Update Cycle (Model)
SPC	Storm Prediction Center
UH	Updraft Helicity
USAF	United States Air Force
VAD	Velocity Azimuth Display
WFIP	Wind Forecast Improvement Project (DOE NOAA program)
WRF	Weather Research and Forecast (Model)



# List of Acronyms (continued)

WSR-88D	Weather Surveillance Radar – 1988, Doppler
WVSS	Water Vapor Sensing System
3D-VAR	Three Dimensional Variational Data Assimilation